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Mid-Atlantic Highlands Streams Assessment:

Technical Support Document

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1.0 Overview/Introduction

1.1 Overview of the Projects that Constitute MAIA Field Sampling from 1993-1998: EMAP, REMAP, and TIME

The EPA Environmental Monitoring and Assessment Program (EMAP) was initiated in the late 1980s in response to its Science Advisory Board's (SAB) report that encouraged the Agency to quantitatively determine the effectiveness of its regulatory programs. The SAB recommended the implementation of a program to monitor ecological status and trends that would identify emerging environmental problems before they reach crisis proportions (Science Advisory Board 1988). EMAP became a multi-agency activity to evaluate the ecological status of terrestrial and aquatic ecosystems. The following three objectives have guided the EMAP research activities since that time (Lazorchak et al. 1998):

- Estimate the current status, extent, changes and trends in indicators of the condition of the nation's ecological resources on a regional basis with known confidence.
- Monitor indicators of pollutant exposure and habitat condition and seek associations between human-induced stresses and ecological condition.
- Provide periodic statistical summaries and interpretive reports on ecological status and trends to resource managers and the public.

1.1.1 Mid-Atlantic Highlands Assessment Project

The stream sampling component of EMAP-SW was initiated in 1993 in the mid-Appalachian region of the eastern United States; it specifically focused on the all of the Highlands in Region 3 west of the Blue Ridge Mountains. It was carried out in conjunction with a Regional-EMAP (R-EMAP) project that emphasized the Ridge and Valley regions and the TIME program (see below) to address acid-sensitive systems in the Appalachian spine. The designs of these three projects were blended into one assessment program for 1993 and 1994 that is known as the Mid-Atlantic Highlands Assessment study (MAHA), that was carried out over a 4-year period. The MAHA project was designed to test the EMAP approach in a few of the most heavily impacted ecoregions of Region 3, the mid-Appalachians, the Ridge and Valley, and the Central Appalachians (Lazorchak et al. 1998).

The Region 3 R-EMAP project was designed to answer the following questions:

What are biological reference conditions for the Central Appalachian Ridge and Valley Ecoregion?
Do biological communities differ between subregions?
What is the status of Mid-Atlantic Highlands stream biota?
Can linkages be established between impairment and possible causes of impairment?

During the MAHA study, 550 wadeable stream sites predominately in the western two-thirds of EPA Region 3 (DE, MD, VA, WV, PA) and the Catskill Mountains of New York were visited and sampled using the field protocols being developed by EMAP. Streams were sampled each year during a 10-week index period from April to July by field crews from EPA, the U.S. Fish and Wildlife Service, State, and contract personnel.

1.1.2 Temporal Integrated Monitoring of Ecosystems Project

A special interest component of EMAP-SW is the Temporal Integrated Monitoring of Ecosystems Project (TIME). The purpose of the TIME project is to assess the changes and trends in chemical condition in acid-sensitive surface waters (lakes and streams) of the northeastern and eastern U.S. resulting from changes in acidic deposition caused by the 1990 Clean Air Act Amendments.

Components of this program were included in the 1993-1994 MAHA program. The TIME project has three goals:

Monitor current status and trends in chemical indicators of acidification in acid-sensitive regions of the U.S.
Relate changes in deposition to changes in surface water conditions.
Assess the effectiveness of the Clean Air Act emissions reductions in improving the acid/base status of surface waters.

1.1.3 Mid-Atlantic Integrated Assessment Program

From 1995 to the present, the EMAP Surface Waters Program became a collaborator with R-EMAP and TIME, and the partnership was called the Mid-Atlantic Integrated Assessment (MAIA) project, which is attempting to produce an assessment of the condition of surface water and estuarine resources. The MAIA project represented a follow-up to the MAHA study, with an expanded geographic scope (southern New York to northern North Carolina, with more sites located in the Piedmont and Coastal Plain ecoregions) and a different index period (July-September). In 1997, the first year of the MAIA study, approximately 200 sites (150 wadeable sites, 21 repeated wadeable sites, and approximately 30 riverine sites) were visited for sampling.

1.2 Physical/Geographic Setting of the Mid-Atlantic Highlands

The focus of the MAHA Streams report is on the condition of first, second, and third-order streams which constitute approximately 89% (72,000 miles) of all streams in the Highlands. The Mid-Atlantic Highlands contain parts of eight distinct Level III ecoregions (see Figure 1-1). For the MAHA State of the Streams report, similar Level III ecoregions were combined into four ecoregions to generate sufficient sample sizes to make estimates of stream condition. The four ecoregions are (1) Valley ecoregion, (2) Ridge and Blue Ridge ecoregion, (3) North-Central and Central Appalachian ecoregion, and (4) Western Appalachian ecoregion. The following descriptions of these four ecoregions are excerpted from Woods et al. (1999).

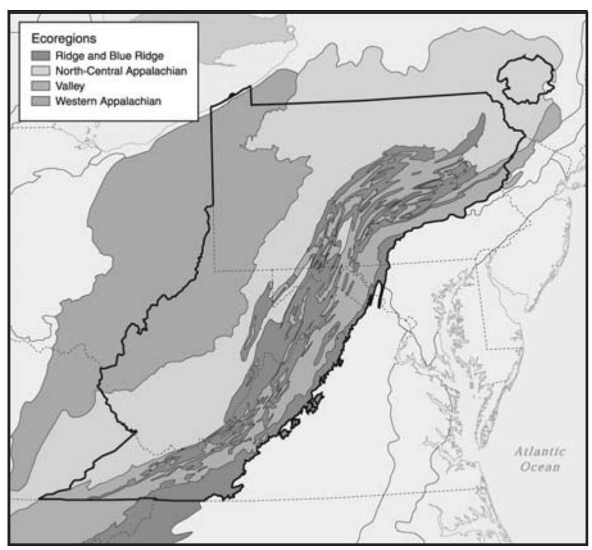

Figure 1-1. Ecoregions of the MAHA region.

Valley Ecoregion: The Valley ecoregion extends from eastern Pennsylvania southwesterly through southwestern Virginia. It is characterized by agricultural valleys that are elongated, folded and faulted which alternate with the ridges of the Ridge and Blue Ridge ecoregion. Local relief varies from approximately 50 to 500 feet. The ecoregion narrows toward the south and is generally bordered by the higher Blue Ridge Mountains and the higher and less deformed Allegheny and Cumberland plateaus. The ecoregion is underlain largely by Paleozoic sedimentary rocks that have been folded and faulted. Sandstone, shale, limestone, and dolomite are the predominant rock types. Lithological characteristics often determine surface morphology. Valleys tend to be created on weaker strata, including limestone and shale. Inceptisols and Ultisols are common and were developed on noncarbonate rock. Alfisols and Ultisols are found in the limestone valleys.

The valleys vary in microtopography and agricultural potential. Those derived from limestone and dolomite are smoother in form and have a lower drainage density than those developed in shale. Shale valleys often display a distinctive rolling topography. Soils derived from limestone are fertile and well suited to agriculture, while those derived from shale have a much lower agricultural potential unless they are calcareous. The nutrient rich limestone valleys contain productive agricultural land and tend to have few streams, and stream flows have little association with the sizes of the watersheds. In contrast, the shale valleys are generally less productive, more irregular, and have greater densities of streams. Most of the streams in the limestone valleys are colder and flow all year, whereas those in the shale valleys tend to lack flow in dry periods. Poultry operations are locally common and economically important.

Many of the stream networks are trellised; topography dictates that the swift, actively down-cutting streams which run off steep ridges join the gentle valleys perpendicularly into gentler gradient, warmer, more meandering streams. Partially as a result of the latitudinal extent of the ecoregion, aquatic habitat diversity is good.

Climate varies significantly, and generally, both growing season and precipitation increase southward. The frost-free period varies from less than 120 days to more than 180 days and the precipitation varies from 36 to 50 inches. Locally, however, relief and topographic position have significant effects on the microclimate. The Valley ecoregion is significantly lower than the Central Appalachians, which results in less severe winters, considerably warmer summer temperatures, and lower annual precipitation due to a rain shadow effect.

Ridge and Blue Ridge Ecoregion: The Ridge and Blue Ridge ecoregion is a narrow strip of mountainous ridges that are mostly forested at elevations from approximately 1,000 to 5,700 feet. Local relief varies up to 1,500 feet. This ecoregion contains high gradient, cool, clear streams occurring over mostly sandstone and shale bottoms.

The Blue Ridge portion of the ecoregion to the east is a narrow strip of mountainous ridges that are forested and well dissected. Local relief is high and both the side slopes and the channel gradients are steep. Streams are cool and clear and have many riffle sections; they support a different, less diverse fish assemblage than do the streams of the valleys below, which are warmer, lower in gradient, and more turbid.

The Blue Ridge Mountains are underlain by resistant and deformed metavolcanic, igneous, sedimentary, and metasedimentary rock. Inceptisols, Ultisols, and Alfisols have developed on the Cambrian, Paleozoic, and Precambrian rock. They can be divided into northern and southern parts at the Roanoke River. North of the river, just three different rock types form the crest and the effects of differential erosion partially determine their local altitude. South of the Roanoke River, the Blue Ridge Mountains become higher and lithologically complex.

Climate varies significantly. Generally, both growing season and precipitation increase southward. The frost-free period varies from less than 150 days to more than 175 days, and the precipitation varies from 39 to 49 inches. Locally, however, relief and topographic position have significant effects on the microclimate.

The natural vegetation varies from north to south. North of a transitional area near the Roanoke River, it is predominantly Appalachian Oak Forest (dominated by white and red oaks). South of the transitional area, a mix of Appalachian Oak Forest, Oak-Hickory-Pine Forest (dominants: hickory, longleaf pine, shortleaf pine, loblolly pine, white oak and post oak) grows, and, in higher areas, Northern Hardwoods (dominants: sugar maple, yellow birch, beech, and hemlock). On the foothills, a mix of loblolly and shortleaf pines occur and are mixed with Appalachian Oak Forest.

The ecoregion does not contain any major urban areas and has a low population density. However, due in large part to the close proximity of metropolitan areas in the Coastal Plain and Piedmont regions to the east, recreational development in the ecoregion has increased considerably in recent years.

North-Central and Central Appalachian Ecoregion: The North-Central and Central Appalachians in northern and central Pennsylvania and central West Virginia are a vast elevated plateau of high hills, open valleys, and low mountains with sandstone, siltstone, and shale geology and coal deposits. To the north (North-Central Appalachians), it is made up of plateau surfaces, high hills, and low mountains, and was only partly glaciated. Both the southwest and the glaciated east are low in comparison to the central section, which rises to a general elevation of about 2,300 feet on erosion resistant sandstones. The climate can be characterized as continental, with cool summers and cold winters. Average annual precipitation is from 33 to 50 inches and there can be as few as 100 days without killing frost, the shortest period in Pennsylvania. Soils are often frigid and are derived from sandstone, shale, and till; they are low in nutrients, and support extensive forests. The original vegetation was primarily Northern Hardwoods (dominants: sugar maple, yellow birch, beech, and hemlock), but scattered Appalachian Oak Forest (dominants: white and red oaks) and isolated highland pockets of spruce/fir forest also occurred. Land use activities are generally tied to forestry and recreation but some coal and gas extraction occurs in the west.

The southern portion of this ecoregion (Central Appalachians) includes parts of south central Pennsylvania, eastern West Virginia, western Maryland, and southwestern Virginia. It is a high, dissected, and rugged plateau made up of sandstone, shale, conglomerate, and coal of Pennsylvanian and Mississippian age. The plateau is locally punctuated by a limestone valley and a few anticlinal ridges. Its soils have developed from residuum and are mostly frigid and mesic Ultisols and Inceptisols. Local relief varies from less than 50 feet in mountain glades to over 1,950 feet in watergaps where high-gradient streams are common. Crestal elevations generally increase towards the east and range from about 1,200 feet to 4,600 feet. Elevations can be high enough to insure a short growing season, a great amount of rainfall, and extensive forest cover. In lower, less rugged areas, more dairy and livestock farms occur, but they are still interspersed with woodland. Bituminous coal mines are common and associated stream siltation and acidification have occurred.

Much of the eastern part of the ecoregion is farmed and in pasture, with hay and grain for dairy cattle being the principal crops. There also are large areas containing oak and northern hardwood forests. Land use activities are generally related to forestry and recreation, but some coal and gas extraction occurs in the west. The southern part of the ecoregion in West Virginia is primarily a forested plateau composed of sandstone and shale geology and coal deposits. Due to the rugged terrain, cool climate, and infertile soils, this area is more forested and contains much less agriculture than does the Valley and Western Appalachian ecoregions. Coal mining is a major industry in this region and acid mine drainage and stream siltation associated with coal mining is common.

Western Appalachian Ecoregion: The Western Appalachian ecoregion extends from southwestern Pennsylvania into western West Virginia. The hilly and wooded terrain of this ecoregion is less rugged and not as forested as are the ecoregions to the east. Much of this region has been mined for bituminous coal. Once covered by a maple-beech-birch forest, this region is now largely in farms, many of which are dairy operations. This ecoregion is characterized by low rounded hills and extensive areas of wetlands.

The Western Appalachian ecoregion is a mostly unglaciated, dissected plateau with 200 to 750 feet of local relief and crestal elevations of less than 2,000 feet. The region is composed of horizontally bedded sedimentary rock. Soils have developed from residuum and support a potential natural vegetation of Appalachian Oak Forest (dominants: white and red oaks) and, especially in the south, Mixed Mesophytic Forest. Land use and land cover is a mosaic of forests, urban-suburban-industrial activity, general farms, dairy and livestock farms, pastures, coal mines, and oil-gas fields. Urban and industrial activity is common in valleys along the major rivers. Bituminous coal mining is widespread and has diminished water quality and reduced fish diversity; recent stream quality improvements have occurred in some rivers including the Allegheny, Monongahela, Youghiogheny, and Ohio Rivers.

The western Appalachians are less forested, warmer, and lower than the North-Central Appalachians. Its border with the Central Appalachians approximates a break in elevation and forest density. It is lower, warmer, less steep, and less densely forested than the Central Appalachians and is underlain by less resistant rock.

1.3 Assessment Questions

Chesapeake Bay and its watershed historically have been a primary focus of EPA Region III and the states because of its environmental and socioeconomic importance to the Mid-Atlantic region. With the emergence of regional issues of acidic deposition, climate change, habitat alteration, and loss of biotic diversity, there has been an increased emphasis on other geographic areas within the Mid-Atlantic by EPA and the states. Other environmental issues affecting aquatic ecosystems are mine drainage, nutrient loading, and fish tissue contamination have been identified through biennial state water quality assessment reports required under Section 305(b) of the Clean Water Act.

The Mid-Atlantic Highland State of the Streams report describes the biological condition of streams throughout the Mid-Atlantic Highland area and documents potential stressors to these stream ecosystems. Geographic patterns in both biological conditions and potential stressors are presented and potential management options are discussed. The later section of the Highland report presents an overview of Highland streams within the Mid-Atlantic region, and within four aggregated ecoregions, by discussing their condition with respect to three levels of potential stressors: acceptable levels, warning levels or levels of concern, and unacceptable levels. Potential management options are then discussed for these three categories of potential stressors.

Preliminary assessment questions were first formulated in 1992 prior to the development of the sampling design. The following three questions were identified:

- What is the biological condition of streams in the Mid-Atlantic Highlands (any patterns to this condition)?

- What is the relative magnitude of the stressors impacting aquatic systems (any patterns to this relative ranking)?

- What is the acidification status of sensitive streams in the Mid-Atlantic?

Once the study design was developed and indicators chosen, a group was formed in 1994 to outline more detailed question that could be addressed with data in hand. A complete set of questions is found in Appendix A-1. These questions have been refined over the succeeding years and used to guide the data analysis and assessment process for Highland streams.

1.4 General Objectives of the MAHA State of Streams Report

The Highland Streams report had five objectives:

1. Assess the ecological condition of streams in the ecoregions and watersheds of the Mid-Atlantic Highlands,
2. Use biological indicators with physical and chemical indicators to describe the condition and characteristics of Highland streams,
3. Produce an objective report on the ecological condition of streams in the Highlands that can contribute to state and regional 305(b) reports,
4. Identify potential stressors that affect stream condition, and
5. Influence state monitoring design and reports in assessing stream condition.

The report was written for an audience of senior administrators, managers, decision makers and informed lay public. The report was not written for a scientific audience so it does not discuss scientific concepts, indicator or index development, techniques, or data analysis procedures. This Technical Support Document presents the underlying scientific basis for the report and the conclusions reached in the Highland Streams report. It draws upon and complements material found in the peer-reviewed literature and, as such, is not intended to contain all the information available on the MAHA program. A companion Technical Feasibility Study on biocriteria, which will be based in part on the MAHA effort, has the objective to further explore the data and analysis methods, and their application to state water quality programs. The content and organization of the Highlands Streams report is shown in Table 1-1.

Table 1-1. Organization and content of the MAHA State of the Streams Report.

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2.0 Program Design

2.1 Overall Basis of EMAP Design

The EMAP Statistical Surveys are designed to collect probability samples that result in the following:
1. Every member of the population has a known probability of being included in the sample;
2. The sample is drawn by some method of random selection consistent with these probabilities, and
3. These probabilities of selection are taken into account in making population estimates from the samples (Snedecor and Cochran 1967).

Using a probabilistic design, samples are collected in direct proportion to their occurrence in the population or resource. The probability of selection does not have to be equal for all members of the population; it is simply sufficient that the probabilities be known. The EMAP stream survey design takes advantage of the attribute of unequal selection of samples as described in later sections. A key feature of probability samples is that the standard error of the estimate, and confidence limits for the true population value, can be computed. If probability samples are collected, it is possible, therefore to determine the accuracy of the estimates and provide estimates of uncertainty (or certainty).

The spatial dispersion of the sample is controlled by using a spatially explicit grid, typically a triangular grid, but rectangular or square grids have also been used. The spatial control of the samples ensures there is adequate spatial coverage across the resource and reduces clumping or aggregations of samples in space. Variable spatial density and nested subsampling permit different sampling intensities to occur within a population, such as sampling first order streams with lower density that higher order streams to ensure a more equitable distribution of samples across stream sizes. In addition, certain areas of interest such as the Ridge and Valley ecoregions can be sampled with greater density, but within the same grid structure used to sample streams across the Mid-Atlantic region (Stevens and Olsen 1999).

EMAP resource sampling typically has occurred within a discrete temporal frame referred to as an index period, but there are no statistical constraints to sampling at any interval. Logistical issues such as time and personnel usually constrain sampling to once or twice per year during index periods. Index periods correspond to a period when sampling can be used to characterize the population or resource to answer a specific set of questions. Different index periods might be selected based on the specific questions being asked. Index sampling is not intended to describe the processes or dynamics of a system over time, but rather to characterize the important attributes of the population or resource and describe the distribution of attributes over the population. Each site is important only as it represents a portion of the population, not because it describes the dynamics at the site.

2.2 EMAP/MAHA Sampling Design

2.2.1 Basic EMAP Mid-Atlantic Grid Design

The elements of the probabilistic design for streams is described in Herlihy et al. (2000). The EMAP grid design was used as the basis of the selection of sample sites. This design is represented by a randomly placed triangular grid of points draped over the continental U.S. and fit within a global framework. The grid points are spaced 27 km apart and, when contiguous hexagons are scribed around each point, a hexagonal sample area of 635 km^2 results. Since this represented a very large sampling area, a finer grid scale was used that allowed for a search area of 40 km^2 (1/16 of the area).

The hexagonal grid selection for the Mid-Atlantic was based on the original consideration of a national four-year stream survey which would have sampled about 800 sites. To ensure enough sites would be accessed and sampled, the Mid-Atlantic area (EPA Region 3) was allocated 100 sites (instead of the 80 for each region), and this comprised the base EMAP sample. These 100 sites (actually 102) are the only ones to have all EMAP parameters sampled.

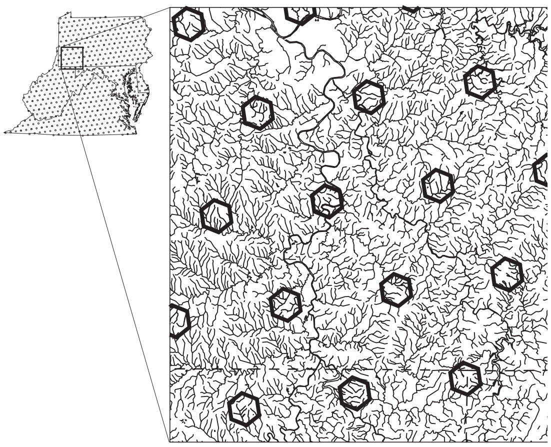

Figure 2-1. Distribution of Stage 1, 1/16 sampling area 40 km^2 hexagons.

2.2.2 First-Stage and Second-Stage Sample Identification

The EMAP hexagonal grid (40km^2) was used along with the EPA Reach File 3 (RF3) representing the hydrography network. The area within this grid consisting of all of the RF3 stream traces is referred to as a "First-Stage Sample". This corresponded to a 1/16 area sample evenly spread across the Mid-Atlantic region (Figure 2-1). Based upon the EMAP four-year rotating design, 1/4 of the hexagons were chosen for sampling in 1993, and another 1/4 in 1994; sample allocation as described below was accomplished separately for each year. The first-stage sample is represented by the identification of all 1st to 3rd order streams contained in the 40 km^2 hexagons.

The second-stage sample was accomplished using GIS and the digital RF3 data. Within each hexagon, all of the digital stream lengths, as stream fragments in the reach file, were identified and mechanically placed in random order along a single continuous line representing all of the stream traces within the hexagon. Fragments within one continuous stream of the same order were kept together. To assure that samples were spread out evenly across the region of interest, the hexagons were placed into spatial clusters, such that each cluster contained approximately the same stream length. Then the hexagons within each cluster were arranged in random order, and finally, the clusters were arranged in random order. In this manner, a random selection of sites along the trace could be made, but it also ensured that sites would not be "clumped" together within certain portions of the Mid-Atlantic region.

2.2.3 Selecting Population of Interest — 1st-3rd Order Streams

Based on the subset of streams of interest, the design was modified for different purposes. For MAHA, the design focused on the 1st, 2^{nd,} and 3rd order wadeable streams. The goal was to sample an equal number of sites from each order stream, however, sampling of the stream traces would yield 60-70% of the samples in the 1st order streams based upon their abundance. Since it was thought that the 1st order streams had a higher probability of being dry or non-target, the 1st order streams were over-sampled and allocated 50% of the sample sites. The 2nd and 3rd order streams were each allocated 25% of the sample sites. Adjustments to the continuous line of stream traces were made to "stretch" streams in each order until the appropriate ratios as a proportion of all stream miles by order in the hexagon were met.

Once the desired factors were applied, a single continuous stream trace was partitioned to randomly select the individual sites to be sampled. For 1993, the length of this "stretched" stream trace (5,090.24 km) was divided by the number of sites for the original base EMAP sample which was 100. The first site was located randomly in the first 50.9 km interval, with each successive site located further down on the trace an distance equal to the interval size.

2.2.4 Intensifying Sample Density

Another modification to the design was intensifying the sample density for the acid deposition stream monitoring (TIME) and the regional-EMAP (R-EMAP) study in the Highlands. A set of six additional hexagons were identified in relation to each of the base 40 km^2 hexagons (see Figure 2-2). This resulted in six additional, but smaller hexagons (13 km^2) which were then used as the frame to extract the stream traces for the first-stage intensified sample sizes. These intensified sites were to be sampled in only certain areas of the region, and thus, the first-stage sample only clipped stream traces from 13 km^2 hexagons in areas of interest. Second-stage sampling was accomplished in the same manner as described above to allocate 150 samples to the intensified design from a 4,638.8 km total intensified stream length (i.e., sample sites identified on a 30.9 km interval).

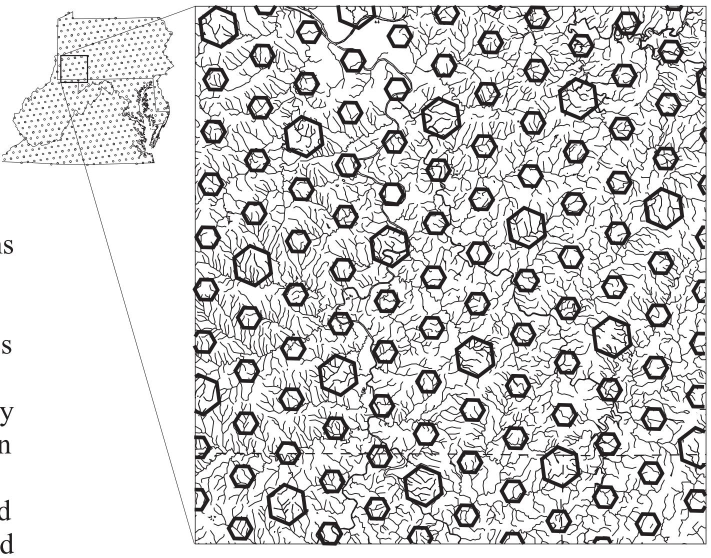

Figure 2-2. Distribution of intensified sample design using 13 km^2 hexagons.

2.2.5 Estimates of Uncertainty

The variance or error in statistical surveys is influenced, primarily, by two factors: the sample size (i.e., the number of samples collected) and the proportion of the samples in selected categories such as acceptable/unacceptable condition. In general, the confidence interval is halved for each four fold increased in sample size. For example, the confidence interval associated with a sample size of 100 when 50% of the population is affected is approximately ± 10%. When the sample size increases to 400 (i.e., 4 fold increase), the confidence interval decreases to approximately ± 5%. The proportion of the population in one of two binary categories also affects the confidence interval with smaller confidence intervals associated with the tails of the distribution and larger confidence intervals associated with the central portion of the distribution.

Confidence limits of estimates of the proportion of stream length exhibiting specified conditions (e.g., proportion of stream length with no fish, proportion stream length degraded) were calculated using the Horvitz-Thompson estimation procedure. For the MAHA data set, region-wide estimates of condition with a sample size of approximately 500 would exhibit 90% confidence limits in the 6-10% range. Large (n-100) and small (n-30) subpopulations had confidence limits in the 7-12% and 12-20% ranges, respectively (Herlihy, personal communication). Population estimates in the central portion of the distribution would have higher confidence limits within these ranges.

2.3 Sites Selected for Sampling

In 1993 and 1994, the MAHA region was sampled at 448 sites. The number of samples collected on the EMAP design grid is designated as Target samples and are shown with parameters measured in Table 2-1. A number of hand-picked sites thought to be in good and bad condition are also shown as Reference and Test sites, respectively. Sample locations, site descriptors and the parameters measured are detailed in Appendix Table A-2 and the complete data set can be found at the MAIA web site streams homepage at:

http://www.epa.gov/emap/html/dataI/surfwatr/data/mastreams/

Table 2-1. Number of samples sites visited parameters measured in the EMAP, R-EMAP, and TIME programs in the Mid-Atlantic 1993-1994.

Parameter	Target	Reference	Test	Total
Macroinvertebrate Assemblage	378	58	10	446
Fish Assemblage	222	58	9	289
Fish Tissue	78	0	0	78
Physical Habitat	101	58	0	159
Rapid Bioassessment	378	58	10	446
Stream Chemistry	378	58	10	446
Dissolved Oxygen/Temperature	101	58	0	159
Watershed Characteristics	380	58	10	448

2.4 Identification of the Sampling Site and Layout of the Sampling Reach

In order to get a representative picture of the ecological community, most of the biological and habitat structure measures require sampling a certain length of a stream. A critical aspect of obtaining a representative sample of the fish assemblage under the proposed plot design was determining the length of stream that must be sampled at each site. For the fish indicator, it was necessary to collect a sample of the assemblage from a single pass through a prescribed length of stream (Karr et al. 1986). Repeated sampling of a stream reach was neither practical nor representative. Thus, to determine the optimal length of stream that should be sampled to maximize the number of different species collected, a small pilot study on a few selected streams was conducted. The results are presented in Figure 2-3. Based on this study, a stream length equal to 40 times the mean channel width was selected as the area to be sampled. This length of stream was sufficient to obtain approximately 90 percent of the fish species inhabiting the reach. Sampling additional lengths of streams did not substantially increase the number of species obtained. This approach was adopted to define the sample reach for all parameters measured in the program.

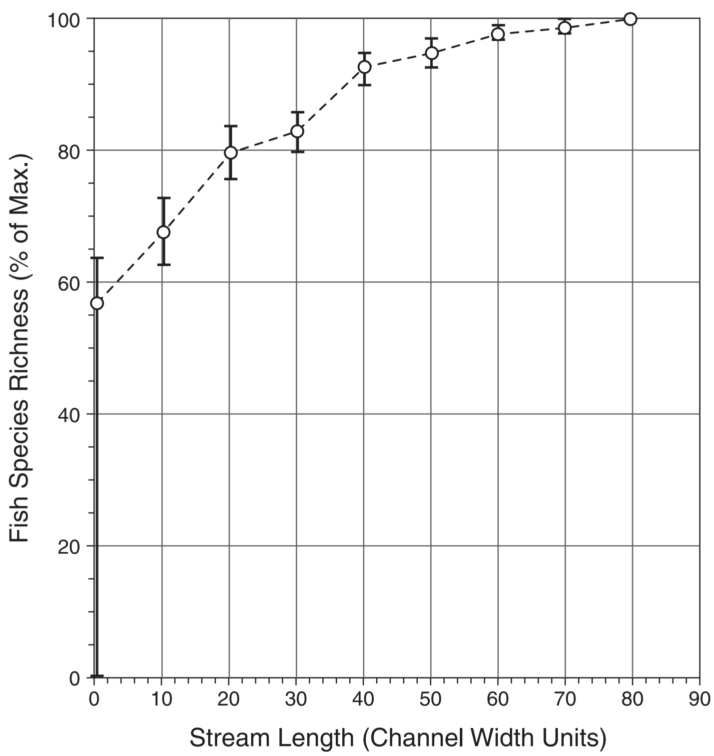

Figure 2-3. Effort-return curve of fish species richness versus length of stream sampled (McCormick and Peck 1999).

Stream sampling points were chosen from the "blue line" stream network represented on 1:100,000- scale USGS maps, following a systematic randomized selection process developed for EMAP stream sampling described above. Sample sites were then marked with an "X" on finer-resolution 1:24,000-scale USGS maps. This spot is referred to as the "index site" or "X-site". Figure 2-4 illustrates the principal features of the established sampling reach, including the location of 11 cross-section transects used for physical habitat characterization, and specific sampling points on each cross-section transect for later collection of periphyton samples and benthic macroinvertebrate samples.

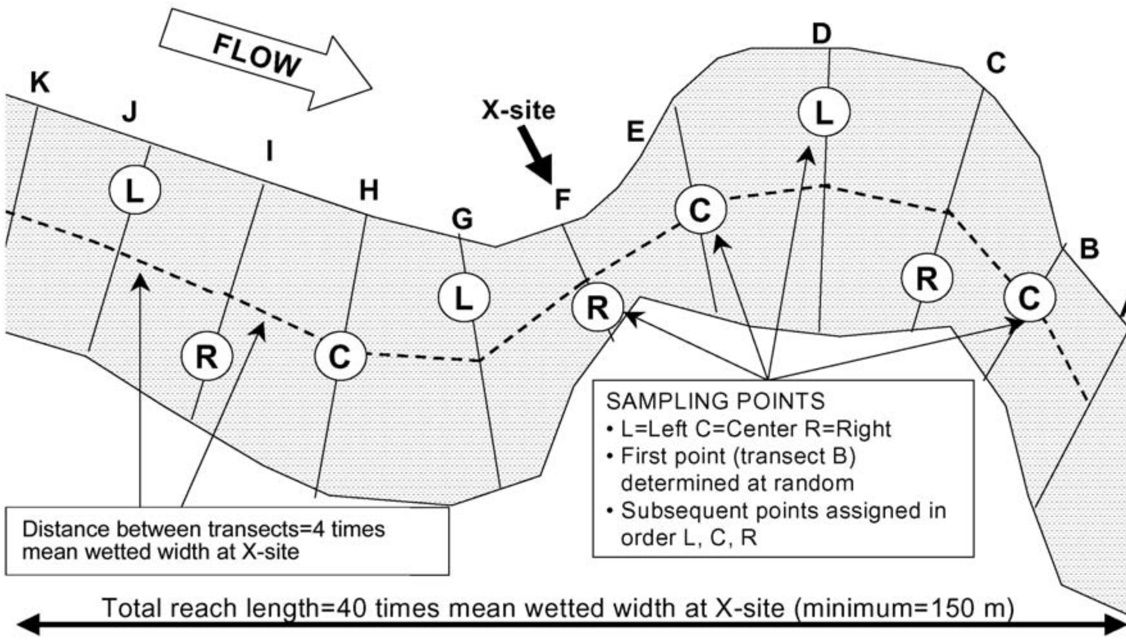

Figure 2-4. Sampling reach features.

Some conditions required adjusting the reach about the X-site (i.e., the X-site was no longer located at the midpoint of the reach) to avoid features that should not be sampled. These features included upstream lower order streams or downstream higher order streams. When these were encountered, the loss of reach length was made up by moving (“sliding”) the other end of the reach an equivalent distance away from the X-site. Similarly, lakes, reservoirs, or ponds were avoided. In any case, the X-site always remained within the sampling reach. If sliding caused the X-site to fall outside the sampling reach, the site was classified as non-target and not sampled.

The full complement of field data and samples were not collected from streams that are categorized as “Dry Channel” or “Intermittent.” Physical habitat information was collected in all streams. Intermittent streams had some cross-sections with biological measurements and some with none. No biological sampling was collected from totally dry channels. Samples and measurements for water chemistry were collected at the X-site (even if the reach has been adjusted by “sliding” it). If the X-site was dry, the sample and chemical measurements were taken from a location having water with a surface area greater than 1 m^2 and a depth greater than 10 cm. All data for the physical habitat indicator were collected from all streams, regardless of the amount of water present in the channel or at the transects. Depth measurements along the deepest part of the channel (the “thalweg”) were obtained along the entire sampling reach for all target streams, whether they were dry, intermittent, or completely flowing. Other measurements associated with characterizing riparian condition, substrate type, etc. were collected to help infer conditions in the stream when water is flowing.

2.5 Indicator Selection

Indicators were selected based upon a framework for indicator interpretation that identified environmental values for streams, relationships to assessment questions, the primary environmental stressors, and critical ecosystem components. The overall process for selecting EMAP indicators is presented in Barber (1994).

The streams program has emphasized biological integrity as the primary environmental value which should be used to describe stream condition. Stressors that potentially affect this condition are deposition of nutrients and chemical contaminants from anthropogenic emissions, alteration of stream physical habitat, contamination of fish, and introduction of exotic species. In the MAHA streams report, biological integrity is represented quantitatively by the macroinvertebrate and fish indices of biotic integrity. Acid-neutralizing capacity (ANC) and concentrations of nitrogen and phosphorus were used as indicators of mine drainage, acidic deposition, and eutrophication. Indices of riparian habitat quality and channel sedimentation were developed to address the extent of habitat alteration. A watershed risk index was applied to integrate all identifiable stressors that might be affecting wadeable streams. Direct measures of metal and organic contamination in fish and presence of non-native species also were made.

EPA recently has published evaluation guidelines for ecological indicators (Jackson et al. 2000) that specify the criteria an indicator or index must meet in order to perform effectively. Evaluation of stream indicators presented here and in the streams report, according to these performance criteria, is ongoing.

2.6 Reference Conditions

Identification of reference conditions is a critical element in the evaluation of biotic integrity. Reference conditions are expectations on the status of biological communities in the absence of any human disturbance, i.e., the biota exist under ideal, and solely natural, conditions (Plafkin et al.1989, Gerritsen et al. 1994). However, since there are few if any waters not influenced by human activities, other methods for estimating reference conditions, including historical records, best professional judgement, and/or identification of minimally impaired sites, must be employed.

Biological characteristics may be derived from historical records made prior to any human disturbance; this information usually is contained in museum/university collections, water resource agency documents, or the published literature. It is unlikely, however, that biotic condition could be reconstructed from a single complete record and multiple sources of information would be required. A drawback to a historical reconstruction of biotic condition is that multiple information sources likely had multiple objectives and sampling procedures that may not be contemporaneous with methods in current evaluations.

Minimally impaired sites are commonly employed to define reference biotic condition. Often these sites are selected, hand-picked, based on expert opinion, best professional judgement or local knowledge on biotic condition. These sites also can be identified and evaluated as to their unimpaired status based upon measurements of all stressor characteristics that may affect biotic integrity; these are necessary to confirm that stressors do not exceed levels known to cause biological or ecological effects. Because of the pervasiveness of atmospheric deposition and habitat alteration in the MAHA region, sufficient numbers of unimpaired, pristine sites may not exist. In this instance, reference sites can be established as those that are minimally impaired, i.e., they meet relaxed standards of stressor characteristics. It is important to regard the interpretation of biotic condition in this circumstance as less than the ideal and more as a relative measure of impacts. In extreme cases, where minimally impaired sites are lacking, the best sites available are employed to define a best attainable reference condition. This condition generally has no relation to true reference condition.

Another approach to defining reference biotic condition, particularly when undisturbed sites are not available, is to model biotic responses relative to a disturbance gradient in the form of a dose-response curve. Estimates of biotic responses then can be made under minimally disturbed, reference conditions.

Regardless of the approach used, reference condition is classified in such a way that natural factors affecting biotic assemblages are taken into account. Reference conditions specific to ecoregions are the most common form of this classification.

2.7 Temporal Sampling Frame

Stream sample collections and observations reported in the MAHA State of the Streams report were made in 1993 and 1994. EMAP employs an approach whereby samples collected within a multi-year program are taken at the same time each year which is termed the index period. The EMAP stream indicator workgroup concluded that the appropriate time for collection of biotic information was during low flow conditions after leaf out and not following flood events (Hughes 1993).

The index period for sampling Mid-Atlantic streams from 1993 through 1996 was spring base flow. Spring base flow should include contributions from both point and nonpoint sources for nutrients, sediment, and organic loading. This index period also should capture both episodic and chronic sources of acidity from acidic deposition and mine drainage. This period was selected to occur after the streams had started to warm and there was increased biological activity in periphyton, benthos and fish, including collecting spring spawning fish species. Finally, there would be sufficient flow in the streams to collect water samples during a spring index period.

3.0 Fish Assemblage

Development of the fish assemblage metrics and IBI described in this section are after McCormick et al. (2001) and a summary of an IBI workshop held in Corvallis, Oregon 26-28 January 2000 (Stoddard 2000), unless otherwise noted.

3.1 Sample Collection and Processing

All methods for MAHA field sample collections are provided in Lazorchak et al. (1998). Relevant excerpts from these methods are provided below.

Fish were collected according to time and distance criteria using pulsed DC backpack electrofishing supplemented by seining. The reach length was equivalent to 40 times the average channel wetted width at the midpoint of the site and consisted of an approximate minimum to maximum distances of 150 to 500 m. The sample interval was no shorter than 45 minutes and did not last more than 3 hours. Transects were established every 10 channel widths or 15 m. Sampling was initially estimated at a maximum of 3 hours to determine the maximum amount of time that should be spent fishing an area. Due to habitat and structural complexities, actual shock time could be 50-75% of the sampling time. Seining was used to supplement electrofishing if it was felt that the electrofishing may have under represented some species, or if the stream was too deep or turbid for optimal electrofishing efficiency.

Fish were identified in the field to species and were also examined for external anomalies, measured for length of some specimens, and voucher specimens were prepared for taxonomic confirmation and archival. Voucher collections of up to 25 individuals of all species were made, with the smaller and harder to identify species collected more often, with only a few larger species in the voucher samples.

3.2 Historical Perspective

3.2.1 Overview of Human Disturbance and Potential Impacts to Fish Populations

McCormick et al. (2001) have summarized the long history of human impact on the landscape, streams, and fish assemblages of the region (Denevan 1992). Streams in the region have been subjected to stresses from acid deposition, mining, logging, agriculture, and development (Raitz et al. 1984; Jones et al. 1997). Settlement of the Highlands did not begin in earnest until the 1700's as German, Irish, and English immigrants spread from Pennsylvania into Virginia and West Virginia. In the mid-1800's, the advent of rail transportation in the region (1830-1860) and discoveries of anthracite and bituminous coal and oil and gas (1850's) opened the region to major industrial development by the coal, oil, and steel industries. Devastating floods and fires occurred in the watersheds of the Allegheny and Monongahela Rivers around the turn of the century. Clear-cutting allowed the deep humus layer covering the forest floor to dry out, resulting in fires that, in some cases, exposed the underlying bedrock. Agriculture and clear-cutting of highland and valley forests exacerbated soil erosion and sedimentation (U.S. DA 1996). In a recent estimate, active and abandoned coal mining resulted in mine drainage that affected 4,000 km of streams (U.S. EPA 1995). Extensive areas of the Ridge, Blue Ridge, and Appalachian plateaus have poorly buffered soils and steep slopes, which have also made streams draining these areas susceptible to acid precipitation (Herlihy et al. 1993).

Stocking of brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), common carp (*Cyprinus carpio*), and large warmwater species (*Micropterus, Lepomis and Ameiurus* spp.) was conducted by the United States Fish Commission and state agencies (Courtenay et al. 1986; Jenkins and Burkhead 1994). Hatcheries were established in the 1870's to culture trout and warmwater game fishes in response to the loss of native species and public demand for augmented sport fisheries. Other introductions, particularly those of forage fish, occurred to support sport fisheries or as bait bucket transfers (Nico and Fuller 1999). Nonindigenous species constitute as much as 33% of the fish fauna of the Potomac drainage and 48% of the fish species in the upper Kanawha (New) River drainage (Hocutt et al. 1986; Jenkins and Burkhead 1994).

3.2.2 Estimation of pre-Settlement Fish Assemblage Condition

The entire MAHA landscape is assumed to have been forested with old growth interspersed with the occasional openings caused by fire, beaver-clearing, blow downs, and hurricanes. The streams flowed clearly, with minimal stream channelization and incision. Because of a greater channel complexity, storage of sands and silts into well sorted homogeneous patches was likely greater than at present. Large woody debris in and around streams were abundant and caused a heterogeneity of channel slope, cross section, and stream flow. These all contributed to greater habitat complexity and patchiness. Mountain streams were stepped by fallen trees; valley streams meandered and had extensive wetlands, braiding, and logjams. Beaver were abundant and provided openings and nutrients in low-gradient streams and flats of higher gradient streams; therefore, smaller streams were normally heavily shaded.

The fish inhabiting these stream habitats required clear cool/cold waters in the mountains and cool/warm waters in the valleys. Non-native species were absent. Long-lived fishes attained large sizes because human predation was minimal and large persistent pools existed. Brook trout, sculpin, and dace inhabited cold headwater streams, which contained up to eight species in larger first order systems. Additional dace, sucker, and darter species would be found in larger cold/cool streams contributing to a species count of up to 15. Warm headwater streams supported dace in smaller systems and chub, sculpin, and shiners in larger systems. Suckers, shiners, sunfish, darters, and bullhead would have been found in large warm streams, which would have contained up to 20 species.

3.2.3 Conceptual Model of Fish Assemblage Response to Stressors

Component metrics of fish assemblage condition are expected to exhibit hypothesized responses to stressors, which can be monitored at different scales. These metrics also incorporate information from different levels of biological organization. Possible causes of poor condition as determined by the assemblage response can be identified (although specific cause-effect relationships cannot be ascertained) by examining correlative relationships between specific indicators or component metrics and various measures of ecosystem stress (measurement variables or multi-component indicators).

Basic relationships between major structural components and processes of a stream ecosystem and general sources of anthropogenic stressors have been documented. Fish assemblages can be used to demonstrate those stressor-response relationships and to assess condition both in the water column and bottom habitats and to provide information on multiple trophic levels. Specific information on stressors and their relationship to the indicators is presented in Figure 3-1. This graphical approach conceptualizes the hypothesized relationships between stressors and component metrics. This approach is based on a more generalized model originally conceived by Karr et al. (1986). The model has been modified to organize it by types of major stressors (following terminology presented in U.S. EPA 1997). The figure provides a means to show direct linkages between individual metrics and each type of stressor and illustrates the diagnostic capability of the fish assemblage indicators. Low scores for certain component metrics are associated with responses to certain groups of stressors.

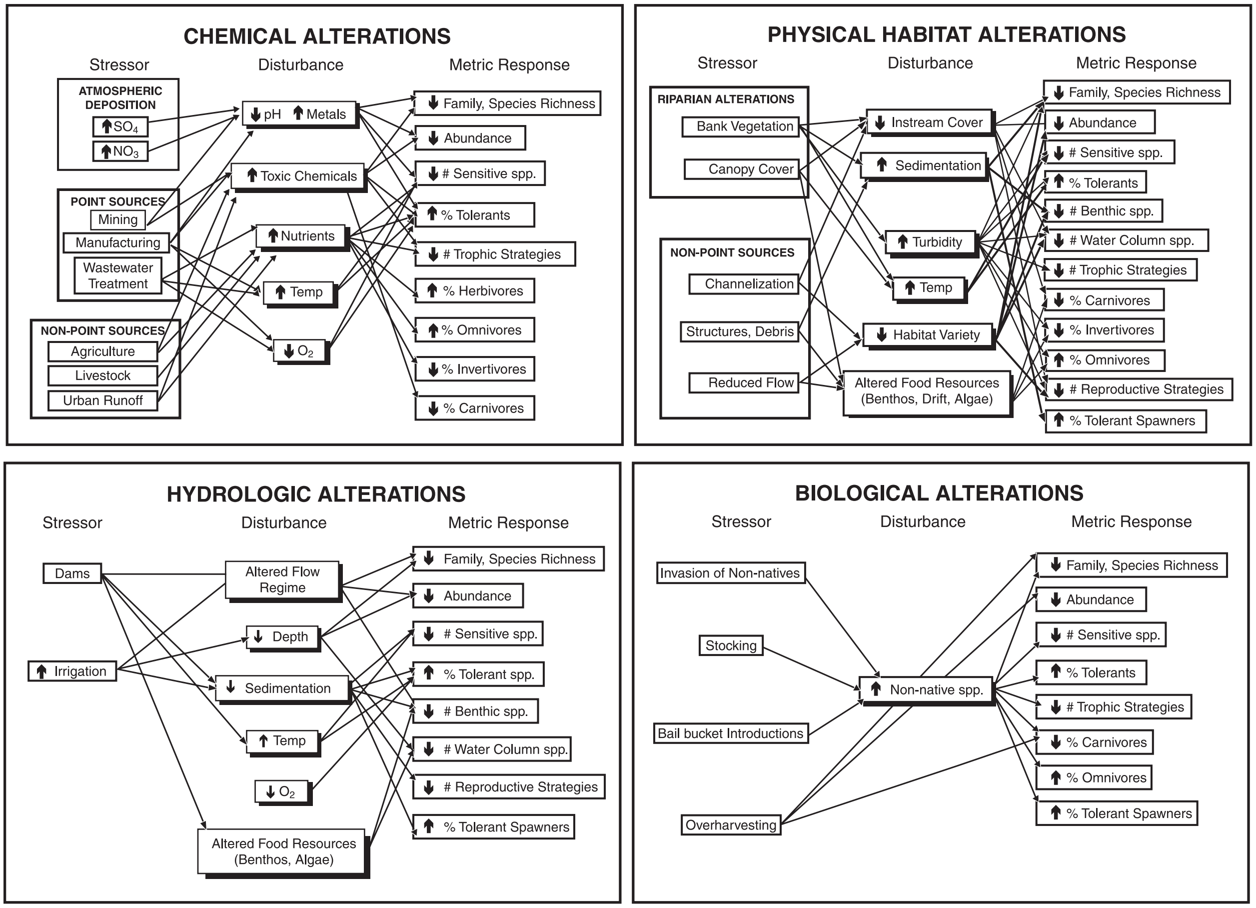

Figure 3-1. Conceptual model of fish assemblage indicators and types of stressors (McCormick and Peck 2000).

3.3 Identification of Candidate Metrics

The fish metric analysis and IBI development contained in the MAHA State of the Streams Report and as described herein are after McCormick et al. (2001). The metric selection and testing, and IBI calculation were developed using a calibration data set which consisted of 177 1993-1996 sites where fish and quantitative physical habitat data were collected. The IBI was tested on 119 remaining sites, which were set aside and not used in IBI development.

Fish were classified into taxonomic, habitat, tolerance, trophic, and reproductive categories for computation of metrics. The classifications of species in an assemblage was limited after Karr (1981) and Karr et al. (1986) in order that neither sensitive nor tolerant species comprised more than 10% of the ichthyofauna. As is common practice (Simon and Lyons 1995), non-native species were retained in the calculation of proportional habitat and trophic metrics but excluded from the richness metrics so as to not artificially desirable attributes. Of the 139 species identified at the drainage basin level, 45 or 32% were considered as non-native, including brown trout and smallmouth bass. The resultant 57 candidate metrics are shown below; 27 are richness metrics and 30 are proportional metrics. Note that each metric is preceded by the data base identifier.

Fish Assemblage Variables

Number of:	
NATIVFAM	families represented
NREPROS	reproductive guilds
NSANGU	anguilla species
NSATHER	atherin species
NSBENT2	native benthic invertivore species minus 3 tolerant taxa**
NSCATO	sucker species
NSCATO2	native intolerant Catostomids
NSCENT	sunfish species
NSCOLU	number of water column species
NSCOTT	sculpin species
NSCYPR2	intolerant cyprinid species
NSDART	darter species
NSDRUMX	drum species
NSESOXX	esox species
NSFUND	fundulus species
NSGAMB	gambusia species
NSICTA	ictalurid species
NSINTOL	intolerant species
NSLAMP	lamprey species
NSPERCO	percopsis species
NSPPER	perch species
NSSALM	trout species
NSUMBR	umbridae species
NTROPH	trophic guilds
NUMFISH	individuals in sample
NUMNATSP	native species
NUMSPEC	total fish species

Proportion of:	
PANOM	individuals with anomalies
PATNG	individuals as attacher non-guarder
BCLN	individuals as broadcast spawners clear substrate
PBCST	individuals as broadcast spawners
PBENT	fish as benthic insectivores
PBENTSP	benthic habitat species in native species
PCARN	piscivore and invertivore
PCGBU	individuals as clear gravel buryers
PCOLD1	cold water individuals
PCOLD2	cold and cool water individuals
PCOLSP	column species in native species
PCOTTID	individuals as cottids
PCYPTL	individuals as tolerant cyprinids
PEXOT	individuals as introduced
PGRAVEL	simple lithophils
PHERB	individuals as herbivores
PINSE	individuals as native insectivores
PINVERT	invertivores
PMACRO	macro-omnivores
PMICRO	micro-omnivores
PMICRO2	micro-omnivores minus RHINATRO
PNEST	individuals as nest associates
PNTGU	individuals as nester guarder
POMNI	omninore individuals (pmicro+pmacro)
POMNI_H	omni-herbivores (pmicro+pmacro+herbiv)
PPISC	individuals as carnivores
PPISCIN2	piscivore-insectivore minus SEMOATRO
PPISCINV	piscivore-insectivores
PTOLE	individuals as tolerant
PTREPRO	tolerant reproductive guild individuals

** *White Sucker (CATOCOMM), Blacknose Dace (RHINATRA), Black Bullhead (AMEIMELA), Yellow Bullhead (AMEINATA), Brown Bullhead (AMEINEBU) were excluded.*

3.4 Analysis and Testing of Candidate Metrics

The 57 metrics were evaluated in a step-wise process that was designed to: assess the effective range of response, evaluate the repeatability of measurements (signal to noise), determine relationship to watershed area and adjust if necessary, identify metrics that provided redundant information, and finally, assess the discriminatory ability of the metrics to disturbance. The following sections describe results of this evaluation.

3.4.1 Test of Range of Metric Values

All richness metrics were subjected to a range test to determine if they had sufficient breadth of values to contribute sufficient information to an fish IBI, i.e., meaningful differences could be detected between reference and impaired sites. The following 13 metrics were eliminated from the list because they only had observed values of 0, 1, or 2:

NSANGU	number anguilla species
NSATHER	number atherin species
NSCATO2	number native intolerant catastomids
NSDRUMX	number drum species
NSESOXX	number esox species
NSFUND	number fundulus species
NSGAMB	number gambusia species
NSICTA	number ictalurid species
NSLAMP	number lamprey species
NSPERCO	number percopsis species
NSPPER	number perch species
NSSALM	number trout species
NSUMBR	number umbridae species

3.4.2 Signal to Noise Ratio Test

Repeated measurements of each metric at the same site were evaluated for the remaining 44 metrics to determine signal to noise ratio. An effective metric should exhibit higher between site variance than within site variance. Two metrics, NTROPH-number trophic guilds and PNEST-proportion of individuals as nest associates, were removed from further evaluation because their signal to noise ratios (between to within site variance) were less than 3.

3.4.3 Relationship to Watershed Size and Correction Procedure

Species richness metrics are known to be related to the size of the watershed drainage area (Fausch et al. 1984). It was determined that if a relationship to watershed size exists, the metric should be corrected before its discriminatory ability was evaluated at a later step in the metric testing framework. The following 17 metrics exhibited a strong relationship to watershed area:

NATIVFAM	number families
NREPROS2	number reproductive guilds
NSBENT2	number native benthic invertivore species minus 3 tolerant taxa
NSCATO	number sucker species
NSCENT	number sunfish species
NSCOLU	number water column species
NSCYPRA2	number intolerant cyprinid species
NSDART	number darter species
NSINTOL	number intolerant species
NUMFISH	number of individuals
NUMNATSPEC	number native species
NUMSPEC	number total species
PATNG	proportion individuals as attacher non-guarders
PBENT	proportion benthic habitat species in native species
PCARN	proportion piscivore and invertivore
PINSE	proportion individuals as native insectivores
PINVERT	proportion invertivores

These seventeen metrics were normalized by regression to a watershed area of 100 km^2 according to the following process. First, the regression for each metric value against watershed size (log_{10}) in predefined reference sites was calculated. This regression was then used at all sites to calculate a residual value for each site. Figure 3-2 demonstrates these steps using the number of benthic species metric as an example. Next, the expected metric value at 100 km^2 was estimated. This value was then applied to the residuals for all sites such that each site/metric value was normalized to the expected value at 100 km^2. Figure 3-3 illustrates this example. Use of this approach is thought to maximize the correction for watershed size without eliminating disturbance factors to which the metrics are responding.

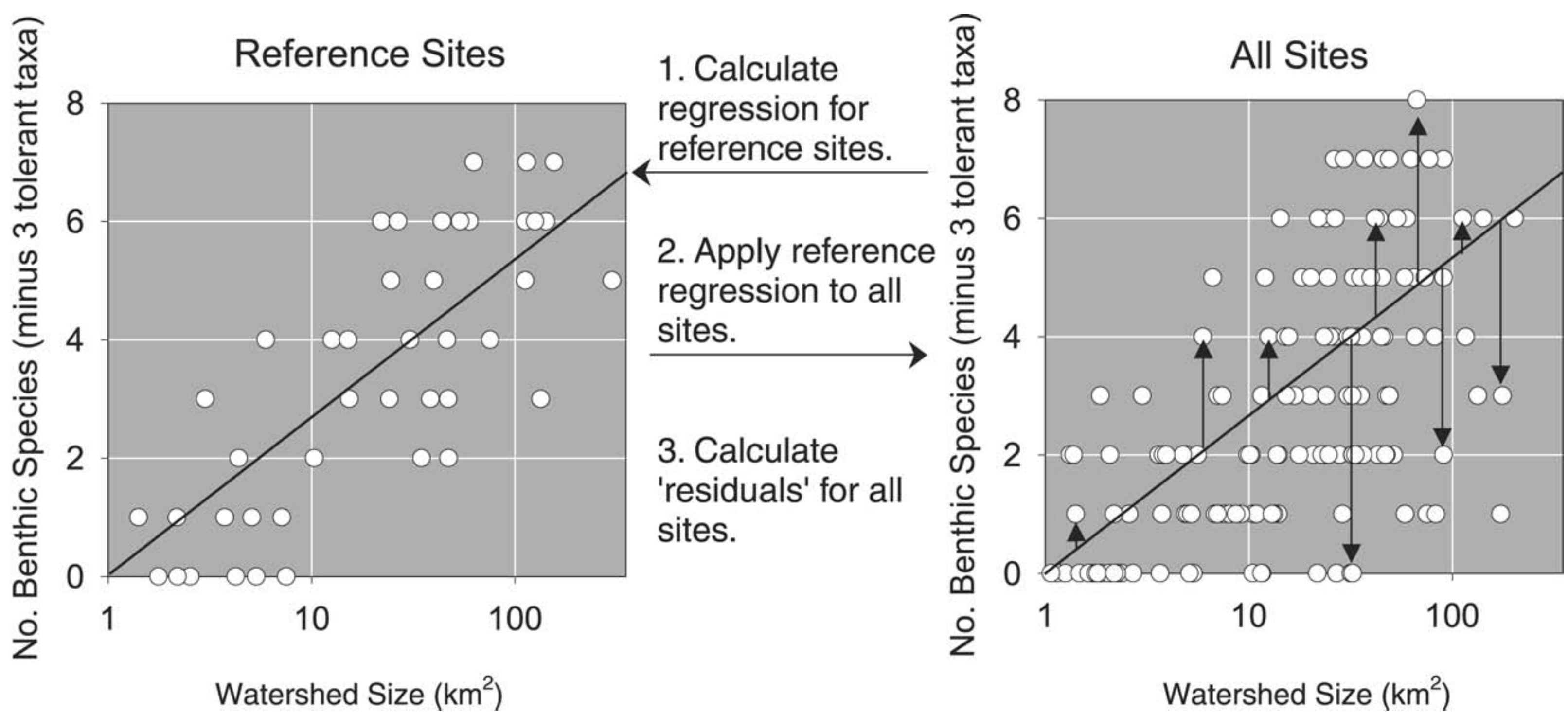

Figure 3-2. Approach to watershed size correction using expected reference value and regression residuals.

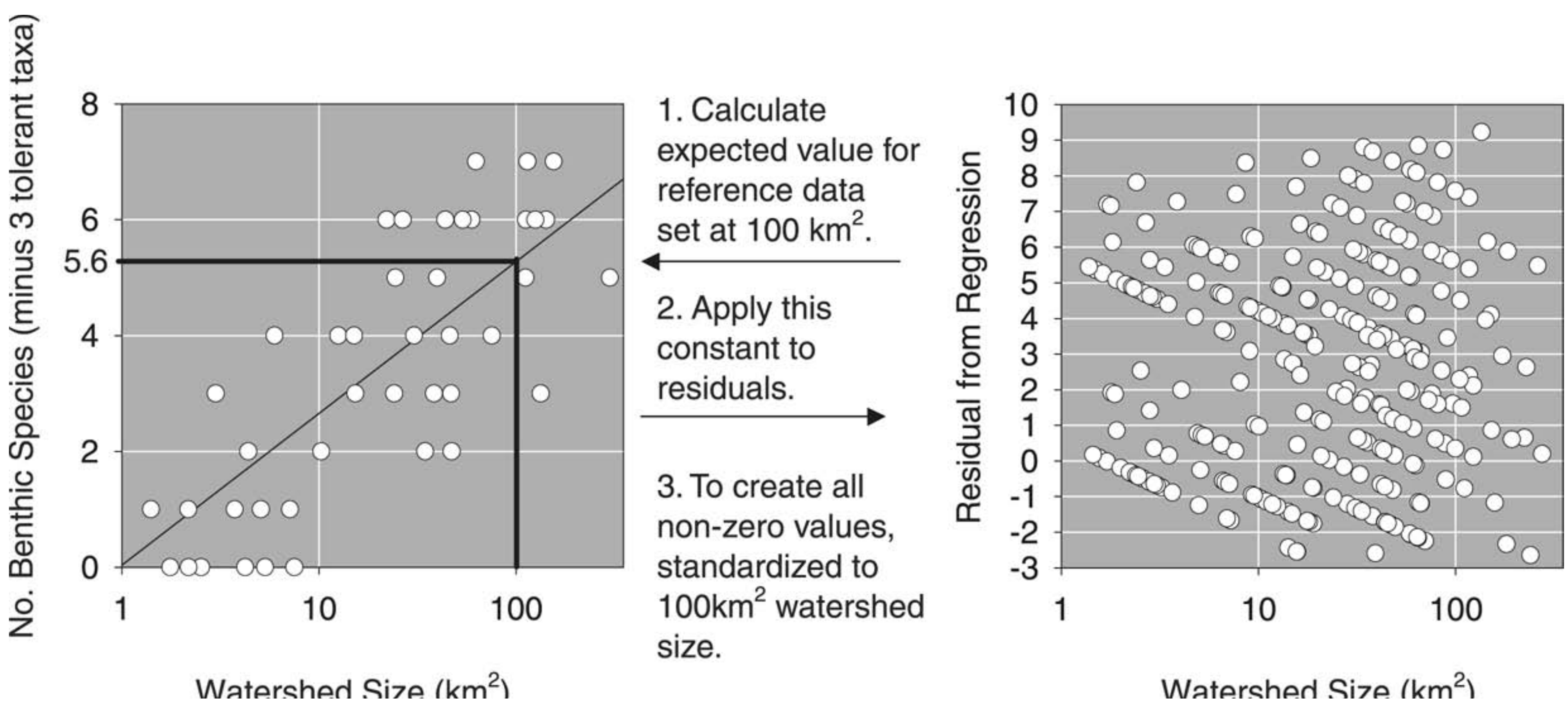

Figure 3-3. Approach to watershed size correction by normalization to 100 km² reference values.

3.4.4 Test of Redundancy

All remaining 42 metrics, were subjected to a correlation analysis to determine their degree of independence from one another. Two pairs of metrics had Pearson Correlation coefficients greater than 0.75. Proportion cold water individuals (PCOLD1) was redundant with proportion of cold and cool water individuals (PCOLD2) and the latter was removed from further testing. Similarly, proportion of individuals as broadcast spawners on clean substrate (PBCLN) was retained in favor of its redundant partner, the proportion macro-omnivores (PMACRO).

3.4.5 Metric Responses to Disturbance

The remaining 40 metrics were evaluated as to their responsiveness in a positive or negative manner to habitat disturbance factors. Habitat disturbance was characterized by the following 18 measures which include, physical, chemical, and catchment parameters:

Chemical	pH
	Sulfate concentration
	Total nitrogen concentration
	Total phosphorus concentration
	Chloride concentration
	Disturbance class
Physical	Percent sands and fines (PCT_SAFN)
	Bed stability (LRBS_BW4)
	Density of large woody debris (XFC_LWD)
	Fish cover
	Riparian disturbance (W1_HALL)
	Channel and riparian disturbance index
	Channel habitat quality index
	Reach slope (XSLOPE)
Catchment	Watershed quality index
	Watershed and riparian condition index
	Watershed, riparian, and channel habitat quality index
	Bryce watershed condition class

Derivation of physical habitat measures is after Kaufmann et al. (1999) and are summarized in Section 5. Condition class is from Bryce et al. (1999) and is described in Section 7. Chemical classification of disturbance class is provided by Herlihy (A. Herlihy, personal communication) and was derived as follows. Sample sites were divided into four classes by water chemistry using a scheme similar to that used by Herlihy et al. (1990, 1991) in previous Mid-Atlantic assessments:

1. Acidic Deposition — ANC < 25 ueq/L AND sulfate < 400 ueq/L
2. AMD Impacts — (ANC < 25 ueq/L AND sulfate > 400 ueq/L) OR sulfate > 1000 ueq/L
3. Mixed Impacts — ANC > 25 ueq/L AND (400<sulfate<1000 ueq/L OR chloride > 100 ueq/L)
4. Least Disturbed — ANC < 25 ueq/L AND sulfate < 400 ueq/L AND chloride < 100 ueq/L

All sites with an ANC below 25 ueq/L were assumed to be acid impacted and assigned to either the acidic deposition or AMD Impacts class using sulfate concentration. Streams with ANC below 25 ueq/L are either chronically acidic (no acid neutralizing capacity; ANC < 0) or usually transiently acidic (ANC 0-25). The dominant acid anion in both acidic deposition and acid mine drainage is sulfate. In the Mid-Atlantic, streamwater sulfate concentrations based on evapoconcentration of sulfate in deposition are expected to be around 150-250 ueq/L. Streams with sulfate below 400 ueq/L have sulfate anion composition dominated by deposition sources. Similarly, streams with sulfate above 400 ueq/L are dominated by internal watershed sources (mining) of sulfate.

Using data from the National Stream Survey (NSS), Herlihy et al. (1990) found that very few acidic NSS stream samples had sulfate concentrations between 250 and 500 ueq/L. Thus, the selection of an arbitrary cutoff value in this range has only a small impact on interpreting the chemical classification scheme. In most acidic streams, the dominant source of sulfate was clearly either atmospheric (stream sulfate less than 250 ueq/L) or from watershed sources (stream sulfate greater than 500 ueq/L).

Dissolved iron or manganese concentrations were not used as a screening factor in the AMD classification because the less acidic mine drainage impacted streams had very low iron concentrations. Sulfate is a better indicator of AMD than Fe because sulfate is a much more conservative ion. Very few processes act to remove sulfate from solution in stream water. On the other hand, iron and manganese rapidly precipitate out of solution (e.g., iron hydroxides or “yellow boy”) as streamwater pH increases downstream from the AMD source. Sulfate concentrations were also used to identify mine drainage impacts in non-acidic streams. Non-acidic streams with sulfate concentrations above 1000 ueq/L in the Appalachian Plateau were classified as non-acidic, mine drainage impacted. All the EMAP sites in the Appalachian Plateau with sulfate greater than 1000 ueq/L had evidence of mining activity in their watersheds on 7.5" USGS maps and/or in the crew field notes. In general, acidic streams are more severely impacted by mine drainage than non-acidic streams because the water itself is toxic to many organisms due to low pH and high metal concentrations. While the water in the non-acidic, mine drainage impacted streams is not necessarily toxic, these sites are often impaired by sedimentation, armoring, sediment metals, and physical habitat alteration due to mine drainage. The high sulfate concentrations in these sites serves as an excellent indicator of mine drainage impacts in the watershed.

In the Mid-Atlantic, stream chloride concentrations are a good indicator of human disturbance in a watershed (Herlihy et al. 1998). Streams with both low chloride and sulfate concentrations and that were not acidic were considered “Least Disturbed” for purposes of this assessment. Chemistry at these sites and visual examination of site maps and field notes indicate that these sites are those with the least human impacts in the region and they could be considered good condition or reference sites. Streams that had chemical signatures too high to make the least disturbed class but not high enough to be considered AMD or acidic deposition impacted were classified as a “Mixed Impacts” class. The streams in the mixed impacts class could be influenced by a number of factors such as roads, point sources, agriculture as well as weak mine drainage.

Nutrient disturbance was deemed high if total phosphorus was > 30 ug/L or total nitrogen was > 1000 ug/L.

Scatterplots and box and whisker plots of each metric against each disturbance factor were visually examined as to response. An example of responsiveness for the metric number of intolerant taxa is illustrated in Figures 3-4 and 3-5.

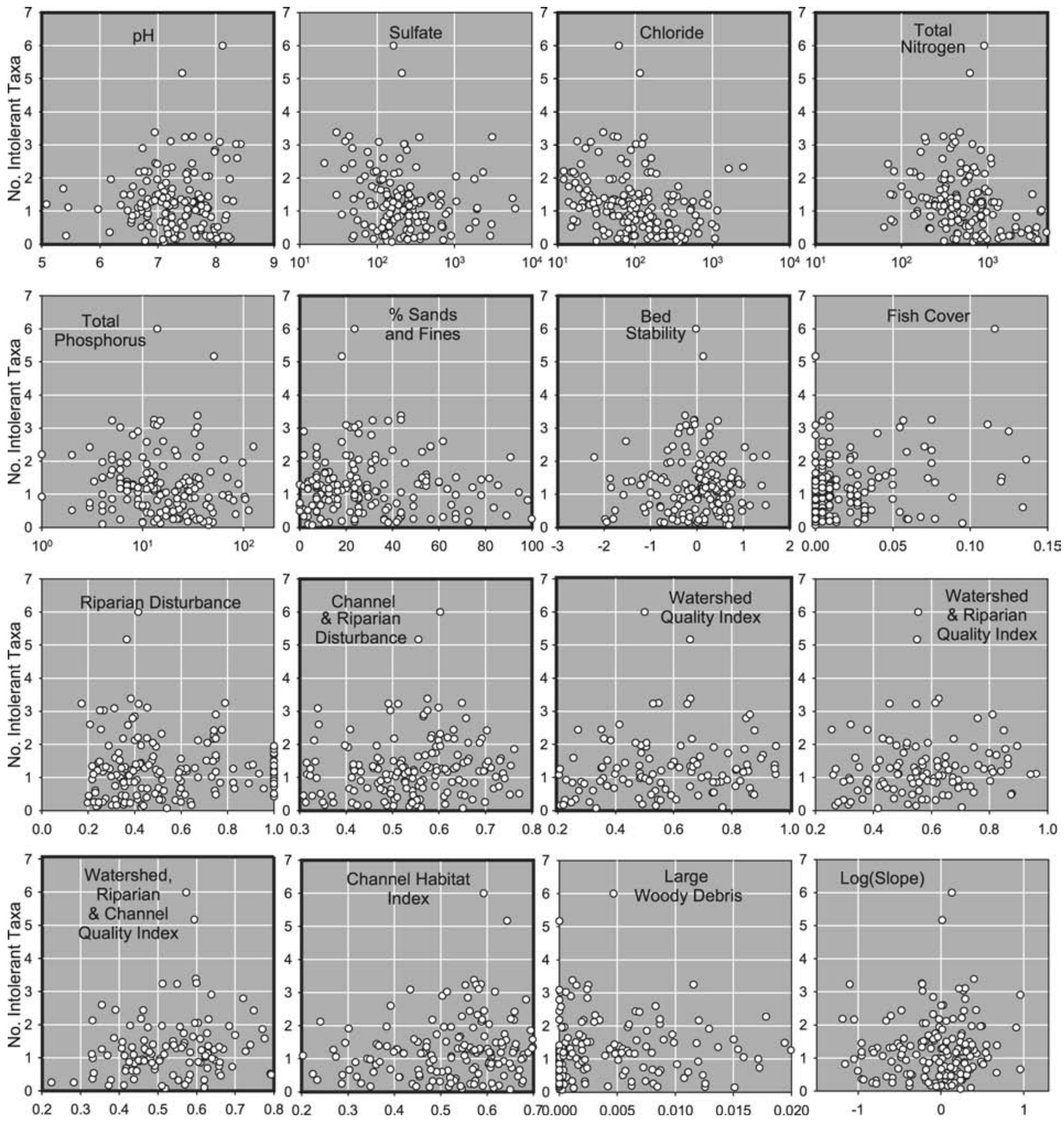

Figure 3-4. Responsiveness of the metric number of intolerant taxa (adjusted for watershed area) to chemical and habitat disturbance factors. Plots **outlined in bold** illustrate good metric response.

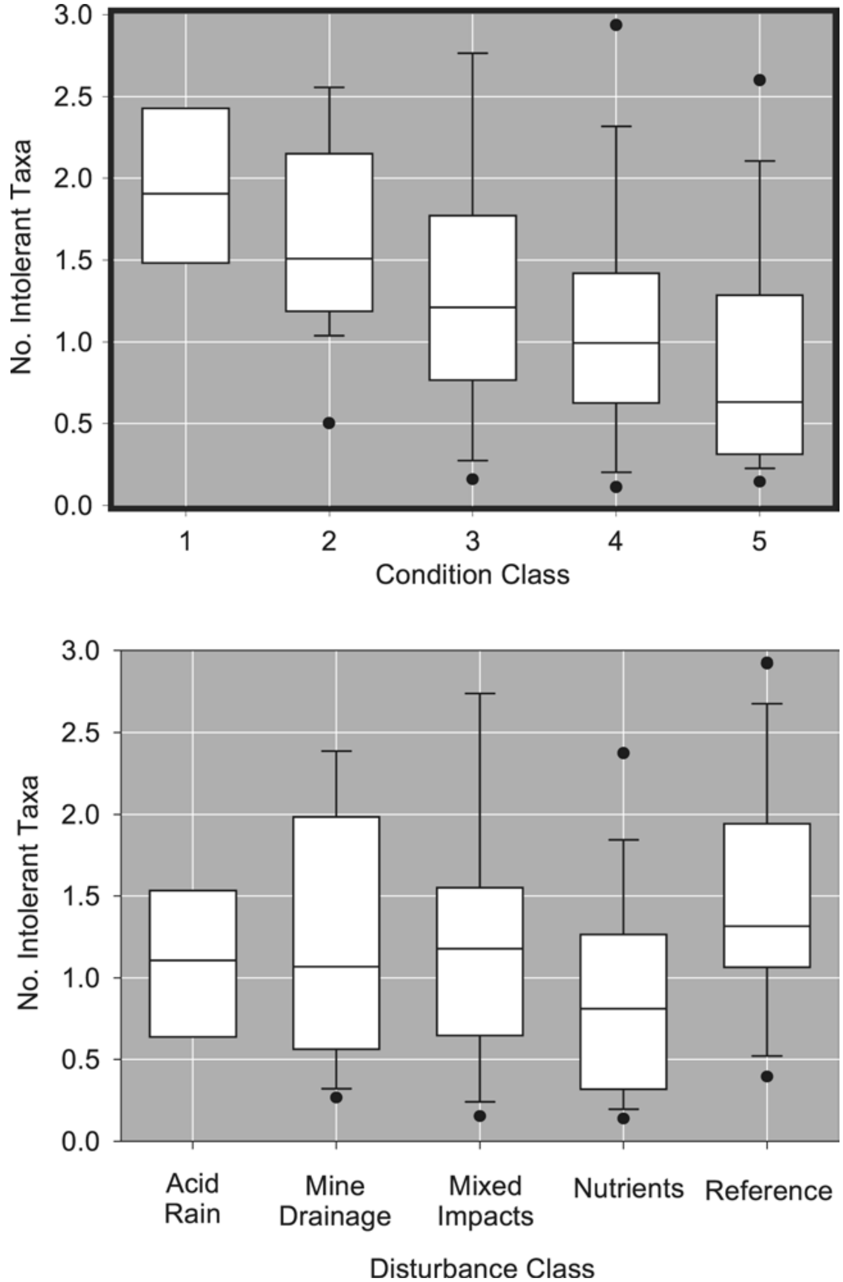

Figure 3-5. Response of the metric number of intolerant taxa (adjusted for watershed size) to integrated measures of habitat disturbance and watershed condition class.

3.5 Metrics Selected and Metric Scoring

3.5.1 Metrics Selected

The 10 most responsive metrics were selected for calibration and scoring using the calibration data set (n=119) as follows. Scatterplots of each metric against each of the 15 individual disturbance metrics (chemistry and habitat), and box and whisker plots of the two integrated measures of disturbance condition class, disturbance class) were examined. Any metrics that showed relationships with two or fewer of these disturbance gradients were discarded. Of the metrics that passed this test, the final metric suite retained for the IBI was composed such that one or more metrics were responsive to each type of disturbance. The selected metrics, listed in Table 3-1, include four proportional metrics and six richness metrics. All richness metrics are adjusted for watershed size.

Table 3-1. Metrics Selected.

Metric Class	Metric Name	Description	Response Class
Tolerance	NSINTOL4	Number Intolerant Taxa	Chemistry, Channel Habitat, Watershed Condition
	PTOLE	Proportion Tolerant Taxa	Chemistry, Channel Habitat, Watershed Condition
Abundance	NUMFISH	Number of Fish	Nutrients
Reproductive	PGRAVEL	Proportion Simple Lithophils	Channel Habitat
Habitat	PCOTTID	Proportion Cottids	Nutrients, All Habitat measures
	NSBENT23	Number Benthic Species	Disturbance Classes
	NSCYPR3	Number Cyprinid Species	Condition Classes
Alien	PEXOT	Proportion Introduced Individuals	Introduced Species
Trophic	PMACRO	Proportion Macro-omnivores	Nutrients
	PPISCIN2	Proportion Piscivore/ Invertevores	All Habitat measures

3.5.2 Metric Scoring

The 10 metrics were scored on a scale of 0-10, with 10 representing the median value of the metric at reference sites, and 0 representing the 10th percentile of the metric values from test (disturbed) sites, all of which were taken from the calibration data set (N=177). Definition of reference and test (disturbed) sites are shown below in Table 3-2. To be classified as a Reference site, all listed criteria must be met and to be defined as a Test (disturbed site), at least one of the criteria must be met.

Table 3-2. Criteria for definition of Reference and Test sites.

Stressor Criterion	Reference	Test
ANC (ueq/L)	>50	
pH		<5
Total Phosphorus (ug/L)	<20	>100
Total Nitrogen (ug/L)	<750	>5000
Chloride (ueq/L)	<100	>1000
Sulfate (ueq/L)	<400	>1000
Mean RBP Score	>15	<10
Habitat Quality Metrics (QTPH1, QCPH1, QW1, QWR1)	>0.5	<0.3
Watershed Condition Class		5

Figure 3-6 demonstrates the derivation of maximum and minimum scores from Reference and Test site equivalent to 10 and 0, respectively, using the number of tolerant taxa metric as an example. In this case, a metric score of 1.5 is equivalent to 10 and values above 1.5 are set to 10. A score of approximately 0.25 is equivalent to 0 and scores lower than 0.25 are set to 0.

In the process of calculating metric scores, one metric, number of fish collected, could not be calibrated, i.e., the median reference value was not different from the test site median. Thus, if scored in a way similar to the other nine metrics, about one-half of the test sites would score a 10. Although the metric passed all other tests, its information content was low, predominantly because of a high degree of variability (Figure 3-7) and increased abundance was not necessarily associated exclusively with either good or impaired condition. This metric was dropped from the IBI suite.

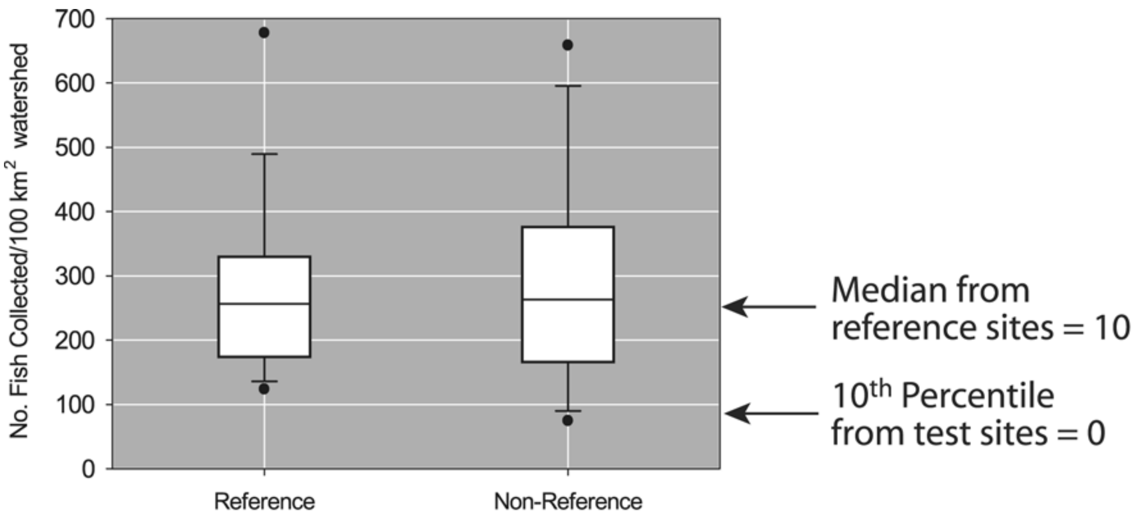

Figure 3-6. Derivation of maximum and minimum metric scores at Reference and Test sites for number of tolerant taxa metric (adjusted).

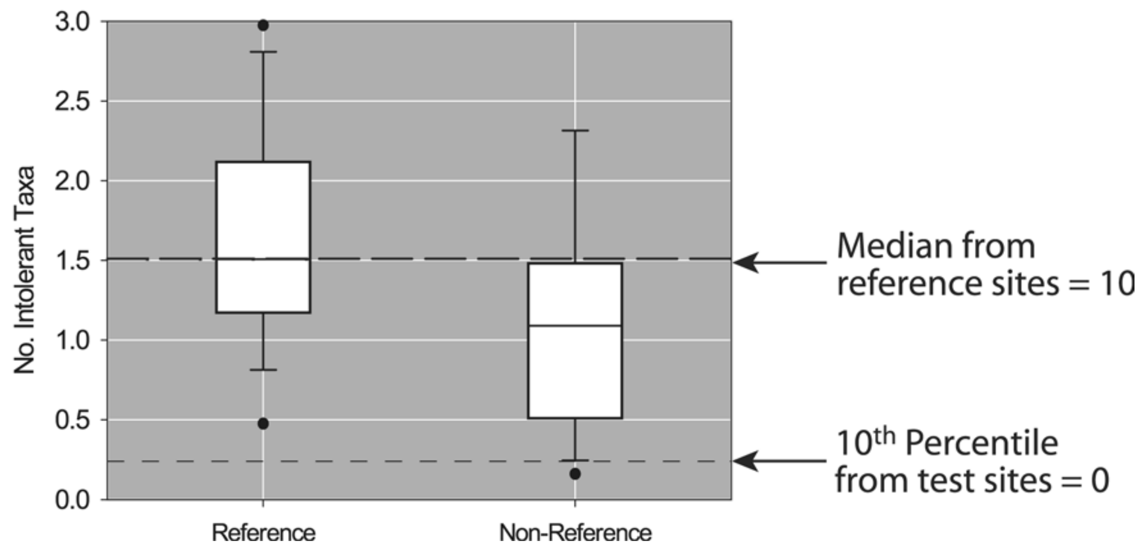

Figure 3-7. Derivation of maximum and minimum metric scores at Reference and Test sites for number of fish collected metric (adjusted).

3.6 IBI Validation and Threshold Development

3.6.1 IBI Validation

The IBI was calculated as the sum of nine [or 10 for some of the examples] metrics. The IBI scores were evaluated against reference and disturbed sites in the validation data set and against the Watershed Disturbance Index from the same data set. In the first comparison, the IBI clearly and statistically distinguished reference from disturbed sites. It also clearly identified high versus low sites as identified by the Watershed Disturbance Index (Figure 3-8). The IBI also was compared to Watershed Condition Class (Bryce et al. 1999) and it demonstrated gradient of response from pristine to degraded condition (Figure 3-9).

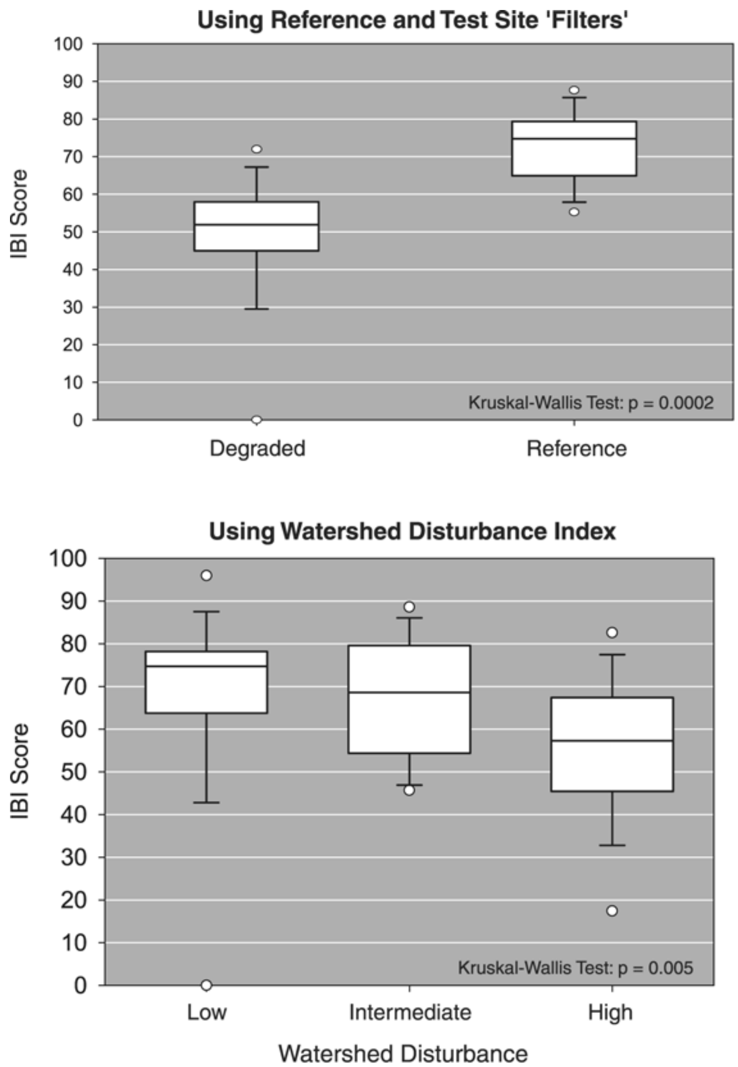

Figure 3-8. Fish IBI scores at reference and degraded sites and compared to Watershed Disturbance Index from the validation data set.

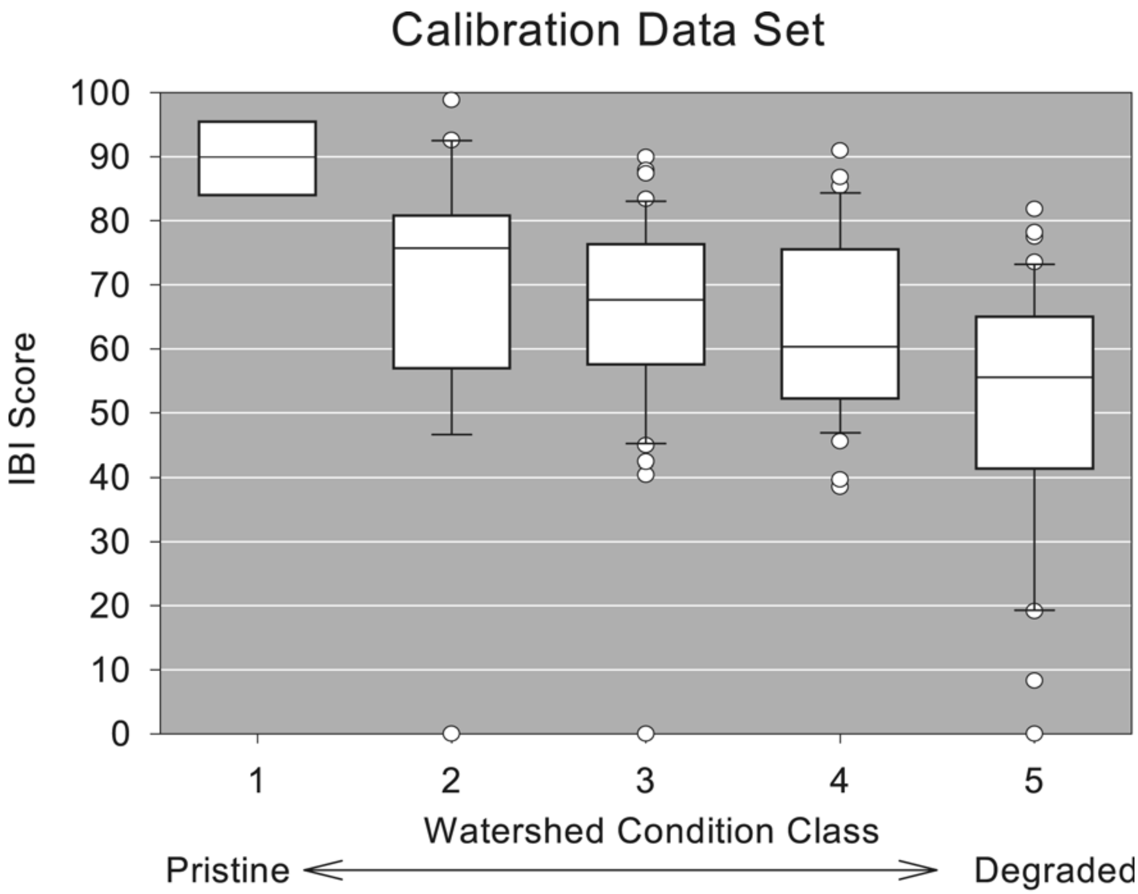

Figure 3-9. Comparison of the Fish IBI to Watershed Condition Class from the calibration data set.

During this validation phase, it was observed that fishless site, which scored 0, were distributed along the disturbance gradient from low to high. This condition is analogous to that described earlier for the metric, number of fish. Number of individuals collected at a site may be low for two reasons:

(1) severe disturbance means the site cannot support many fish; or

(2) sites are naturally low in productivity.

It became apparent that the number of fish collected were directly related to habitat volume, which in turn, is related to watershed size (Figure 3-10). These data indicated that the probability of finding fish at Habitat Volume < 0.4 was very low and furthermore, that these low habitat volumes were all found in watersheds < 2 km^2 (494 acres). Because of this limitation, all fishless sites in watersheds < 2 km^2 in size were excluded from the analysis of condition.

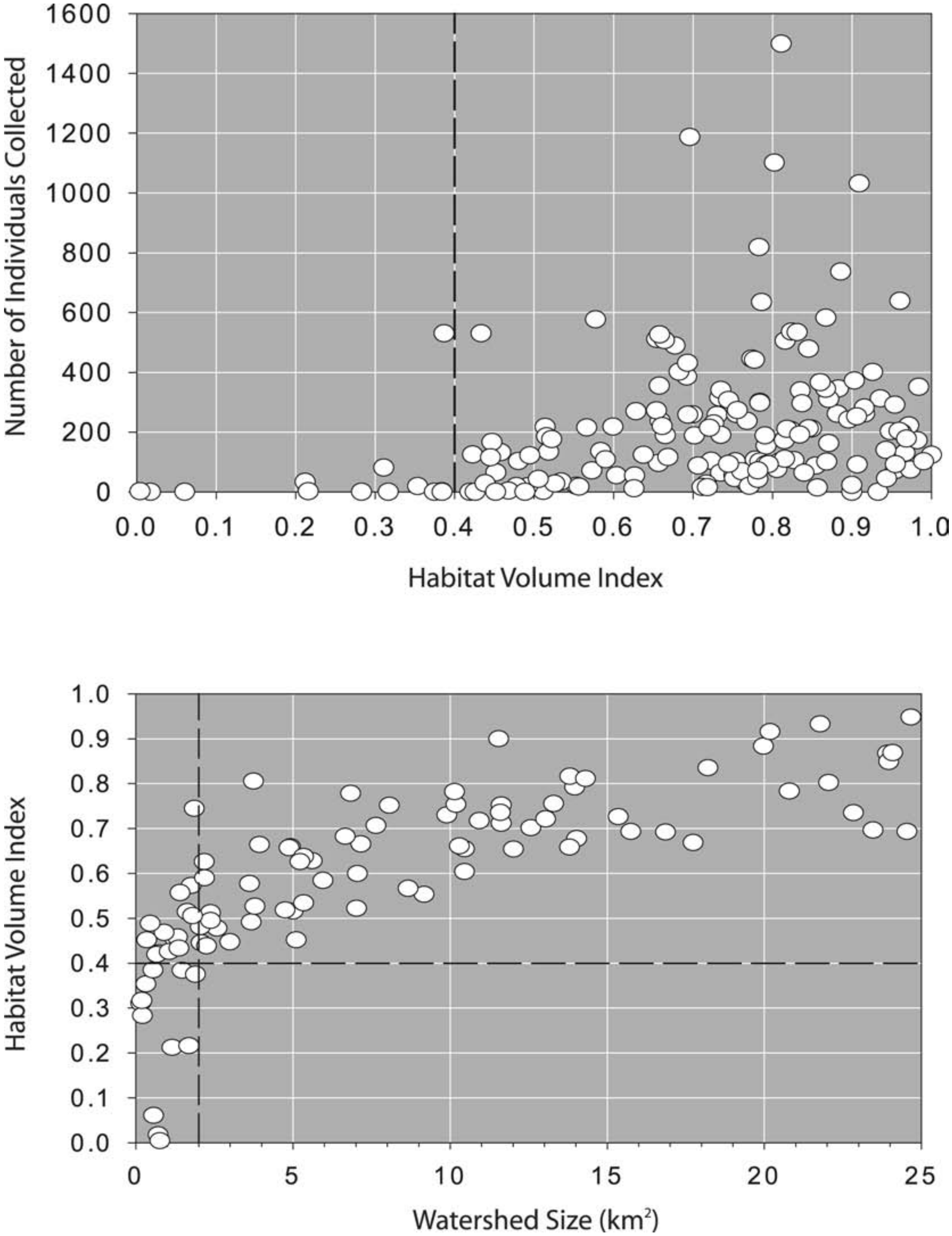

Figure 3-10. Relationship of number of fish collected to habitat volume and habitat volume to watershed size.

3.6.2 Development of IBI Thresholds and Estimation of Condition

The objective of threshold development was to derive IBI values that could be used to categorize stream condition as good, fair, or poor. The distribution of IBI scores at reference sites was used to set these thresholds in the following manner:

IBI > 25th percentile of reference scores = Good
5th < IBI < 25th percentile of reference scores = Fair
IBI < 5th percentile of reference scores = Poor

Three separate reference conditions were identified that ranged from the least restrictive with the most sites included (n=27) to the most restrictive with the least number of sites included. Chemical and RBP habitat criteria were used at all sites (the least restrictive), quantitative habitat filters were added to create the medium level of restriction (n=23), and the most restricted (n=12) further added watershed condition class. In order to acknowledge the uncertainty associated with each of the reference approaches, all three were used. The mean of the 25th percentiles and 5th percentiles were calculated to derive the thresholds as shown in Figure 3-11.

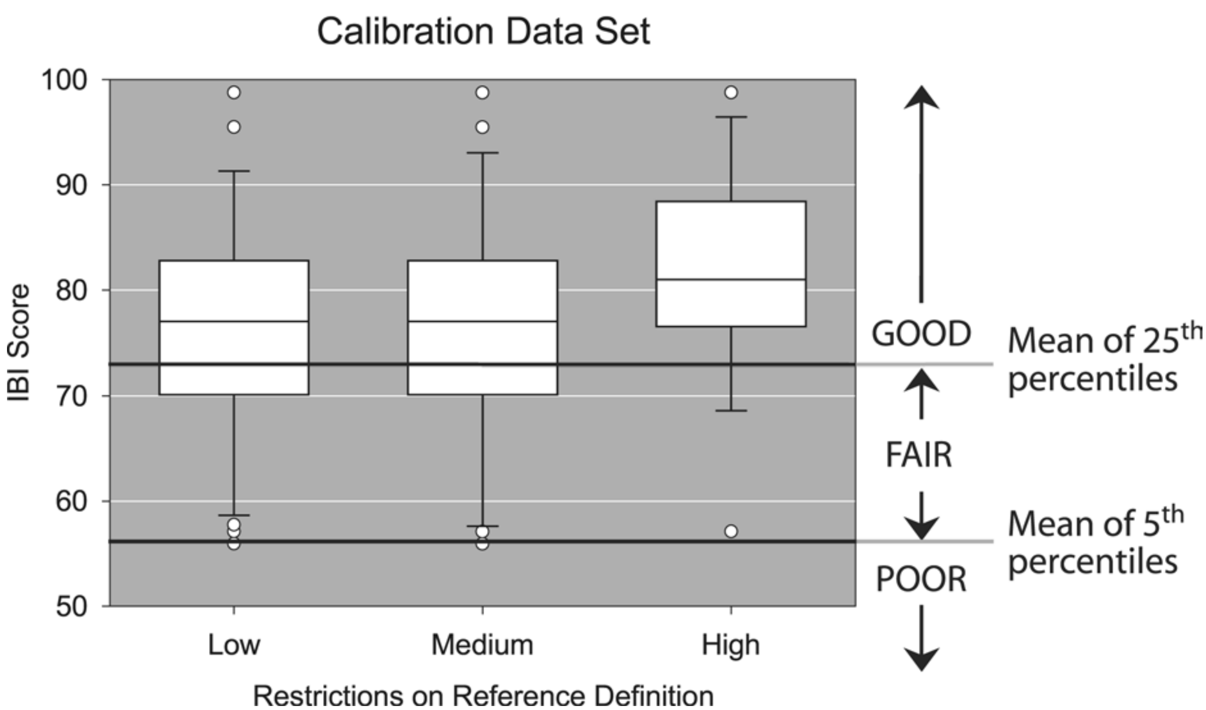

Figure 3-11. Calculation of good-fair-poor thresholds of condition based upon the Fish IBI.

Using these thresholds, stream condition was estimated for the MAHA region; these are shown in Table 3-3. Sites with less than 10 fish observed and watershed area less than 2 km^2 were not included in the assessment and are noted in the “insufficient data” category.

Table 3-3. Estimates of stream condition (% stream length) based upon Fish IBI.

Region	Good	Fair	Poor	Insufficient Data
Western Appalachians	3	32	30	35
North-Central Appalachians	15	32	43	10
Ridge and Blue Ridge	28	44	14	15
Valleys	23	37	31	10
Entire MAHA	17	36	31	17

3.7 Non-Native Species Issue

The objective of the 1972 Clean Water Act is to “restore and maintain the chemical, physical and biological integrity of the Nation’s waters.” To achieve this goal, the Act calls for the formal designation of beneficial uses such as drinking water supply, primary contact recreation (e.g., swimming), and aquatic life support (e.g., fish) for each stream. Each designated use has a unique set of water quality requirements or criteria that must be met for the use to be attained. Some states have created subcategories of aquatic life use for specific types of fisheries, such as cold water fisheries or warm water fisheries, because the public wanted to develop and manage specific fisheries such as brown trout, rainbow trout, or smallmouth bass fisheries in cold and cool water streams. In many streams these fish are not native to the stream or watershed, but rather have been artificially introduced. In these streams, non-native fish have been stocked and are managed by the states for sport fisheries. Presence of non-native fish does not necessarily imply poor stream condition in terms of habitat or water quality, but it does mean the stream does not have a natural fish community which is of interest when assessing biotic integrity and overall ecological condition.

Non-native fish species also can be a potential stressor on the aquatic resource. These introduced species have been known to replace native fish by direct predation or by out-competing them for available habitat or food or both. In the Highlands, approximately 34% of the stream miles have non-native fish species in the fish community. It is important to note that this is a “presence/absence” criterion, and may not represent a level at which stressor effects from introduced species occur. One may also wish to assess effects at different thresholds of non-native individuals proportions (e.g., 10% or 50%).

The definition of biotic integrity used to develop the fish Index of Biotic Integrity reported in this assessment considers the stream to be of lower quality or condition if non-native fish species are present in the stream because it is not the “natural” condition for the stream. Among the purposes of a report like the MAHA report is to simply present quantitative information on topics that ultimately will be debated and decided by society. Many argue that non-native species and their introduction are a serious sign of biological impairment and have significant economic impacts. Others argue that non-native sport fish are highly prized and have an equal economic benefit. The MAHA report presents data from both perspectives. Ultimately, society will be required to make an informed decision on what we want in our streams and rivers.

4.0 Benthic Macroinvertebrate Assemblage

4.1 Sample Collection and Processing

Benthic macroinvertebrates were collected with a modified kick net (Figure 4-1) at each of nine cross-section transects of the sampling reach (approximately 40 times the mean width) (Figure 4-2). Samples were collected from a rectangular area 0.5 m^2 area in front of the net (one net width and two net widths long) by dislodging organisms with a 20-second kick followed by a hand-picking of any larger rocks remaining in the 0.5 m^2 area. Samples for riffle/run and pool/glide were kept separate as individual composites and preserved with ethanol to approximately a 70% final solution. No subsampling in the field was conducted. Figure 4-2 depicts the sampling and compositing design.

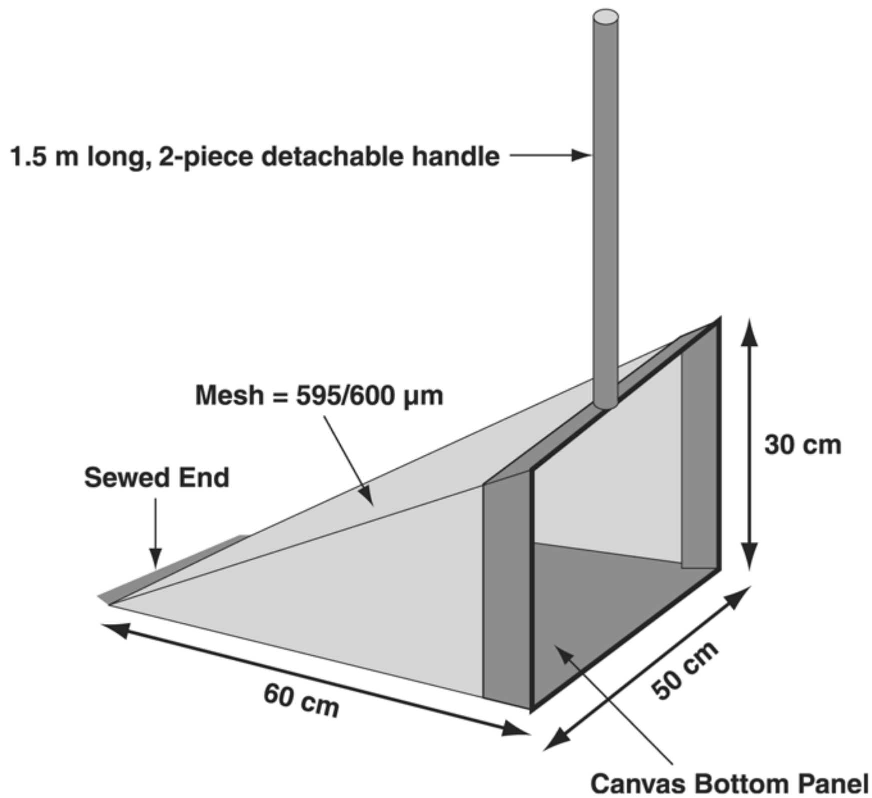

Figure 4-1. Modified kick net for benthic macroinvertebrate sampling.

Of the sites visited for macroinvertebrate sampling, more than 90% had riffles and 40% were pools. Data were collected from a total for 446 sites in 1993 and 1994. Benthic macroinvertebrates were not identified or subsampled in the field. Preserved composite pool and riffle samples were sorted, enumerated, and invertebrates identified to the lowest possible taxonomic level using specified standard keys and references. Analytical methods are based on standard limnological practices. Figure 4-3 portrays the steps in the laboratory analysis.

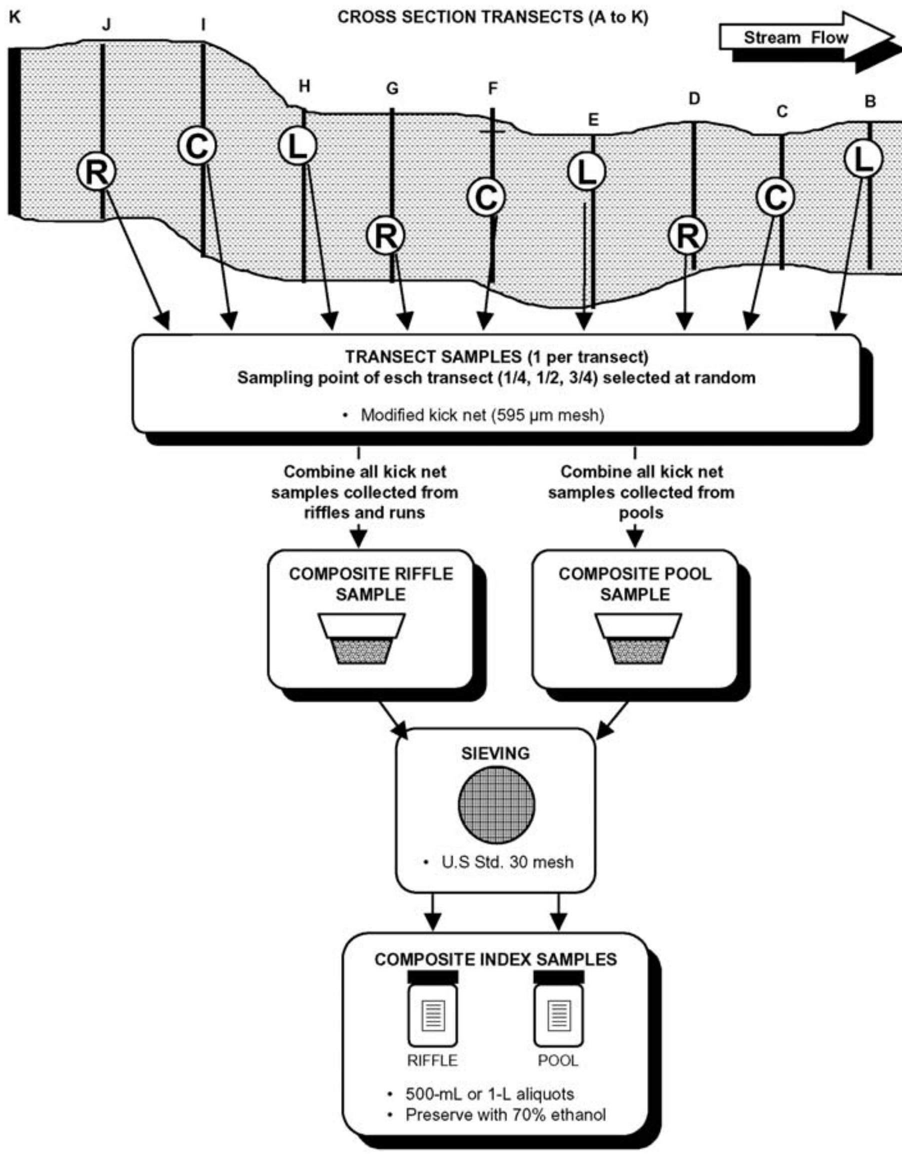

Figure 4-2. Index sampling design for benthic macroinvertebrates.

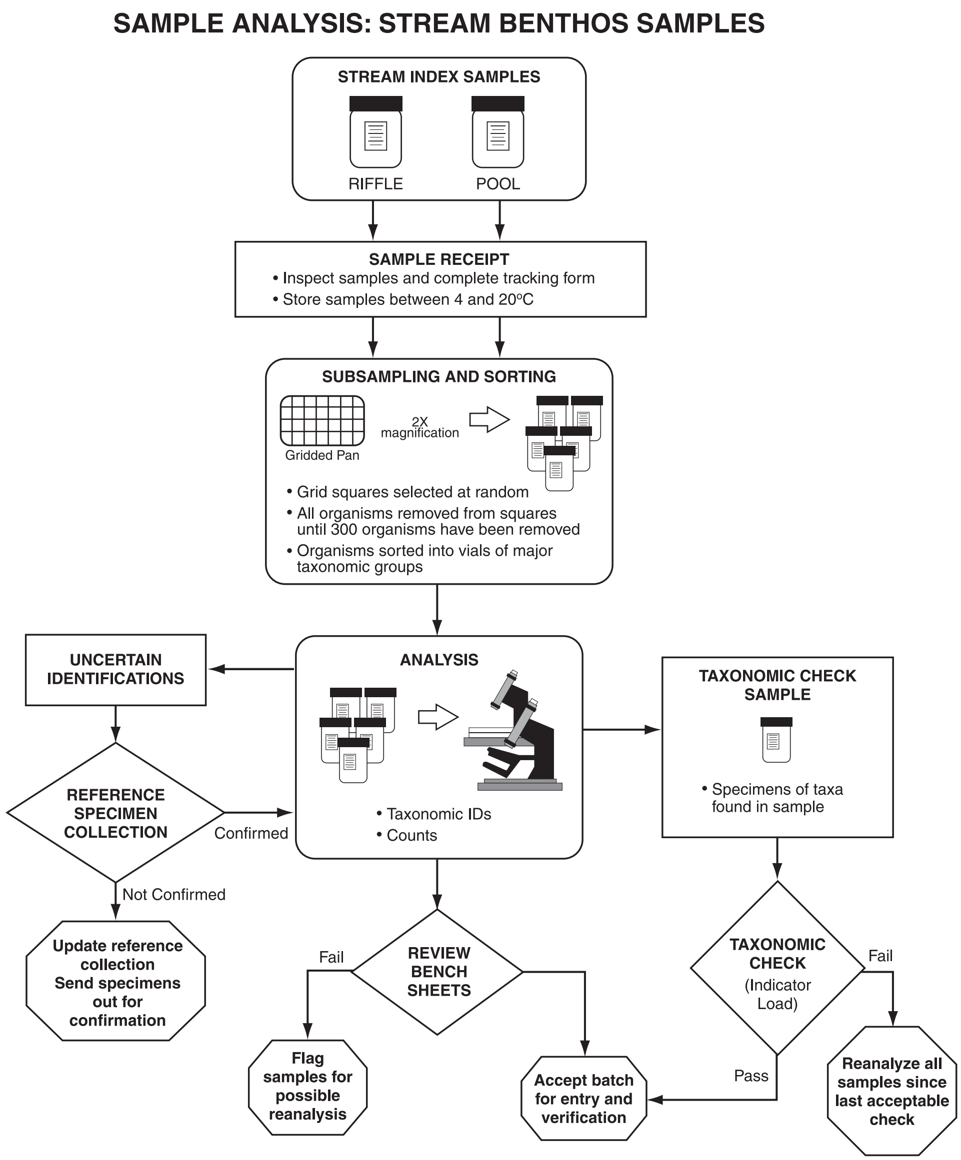

Figure 4-3. Laboratory sample analysis scheme for benthic macroinvertebrates.

4.2 Metric Selection and Testing

Stream condition as represented by macroinvertebrate assemblages was assessed using an EPT index, i.e., number of EPT taxa. This index reflects the number of species found in three orders of aquatic insects, the mayflies (*Ephemeroptera*), stoneflies (*Plecoptera*), and caddis flies (*Trichoptera*). Insects in these three orders are known to be sensitive to pollution and stream disturbance.

A multi-metric index of biotic integrity using macroinvertebrate data is under development. For the purposes of the MAHA State of the Streams report, an EPT metric was used as representative of the metrics being tested and developed. The 46 macroinvertebrate metrics that were evaluated included: 10 richness measures; 22 trophic measures; 13 composition measures; and three tolerance measures.

These metrics were evaluated for inclusion into a multimetric index by using the following procedures:

- box plots
- correlations with stressors
- relationships to watershed size
- extent of redundancy
- PCA with chemistry and physical habitat parameters

The following eight metrics were selected for inclusion in a Stream Benthos Integrity Index (SBII):

- total number of taxa
- modified HBI
- % Plecoptera taxa
- % Oligochaetes/leeches
- % non-insects
- % Chironomid taxa
- % intolerant taxa
- number of EPT taxa

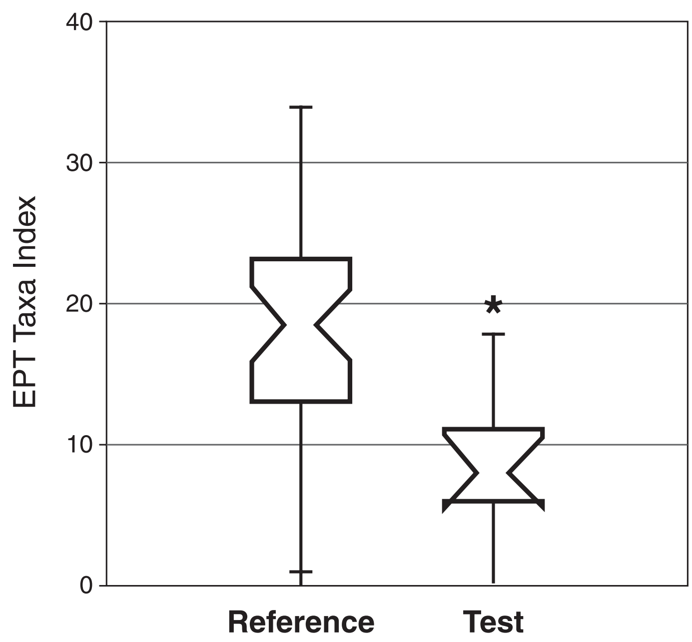

Figure 4-4. EPT taxa index at hand-picked Reference and Test sites.

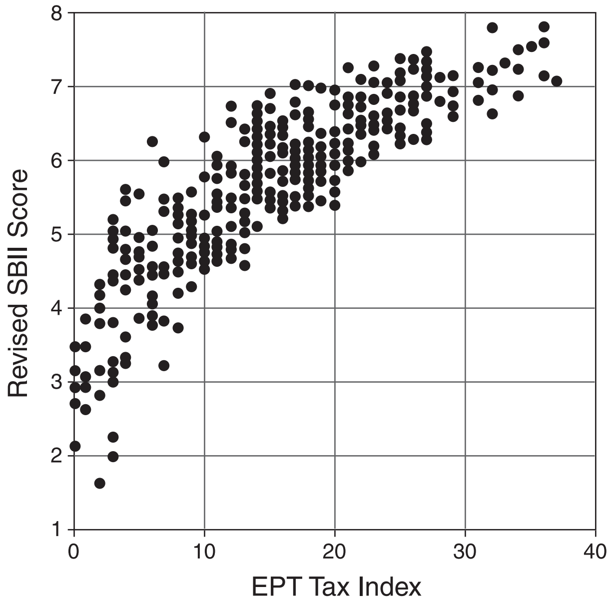

Figure 4-5. Comparison of EPT taxa metric with modified SBII.

4.3 Index Testing

The EPT Index employed in the MAHA streams report was responsive to stressor conditions as represented by conditions at hand-picked Reference and Test sites (Figure 4-4). It also compared favorably with the modified Stream Biotic Integrity Index (SBII) described above. That comparison, shown in Figure 4-5, indicates quite good agreement between the single EPT metric and a multimetric index.

4.4 Reference Condition

The reference condition considered for benthic macroinvertebrate EPT Index was the "minimally-impaired" condition as there is no basis (e.g., museum records, publications) on which to develop a historical reference condition.

A reference site approach was taken for the benthic macroinvertebrates, which examined a subset of the overall number of sample sites based upon various physical and chemical parameters measured during collection. This approach was considered feasible for the macroinvertebrates due to the large number of samples collected and analyzed. The reference sites were developed (filtered) following Waite et al. (2000) using the following reference criteria:

Acid Neutralizing Capacity (ANC) > = 50 ueq/L (ca. = 2.5 mg/l $CaCO_3$)
Chloride (Cl) < 100 ueq/L (ca. = 3.5 mg/l Cl)
Sulfate (SO_4^{2-}) < 400 ueq/L (ca. = 19.2 mg/L SO_4^{2-})
Total P < 20 ug/L
Total N < 750 ug/L
Mean RBP Metric Score > 15 (the mean score of all 12 metrics computed for the site, each ranging from 0-20)

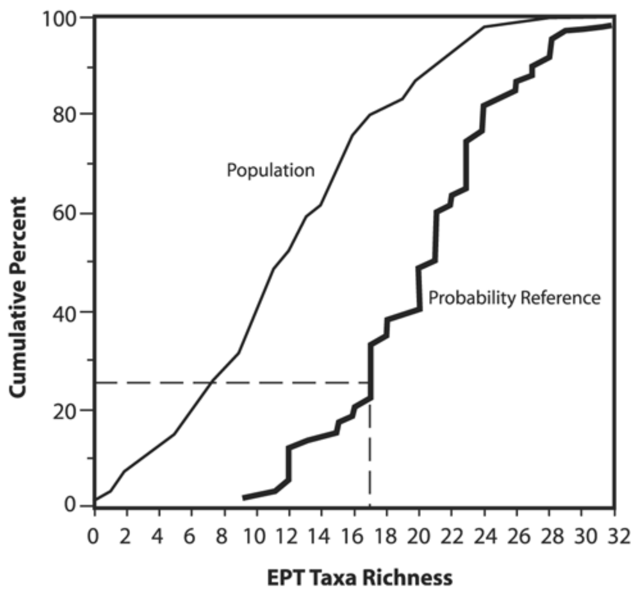

Figure 4-6. Cumulative distribution of EPT Taxa Index scores for all probability sites and filtered Reference sites (from J. Stoddard, unpublished).

Once the reference sites were selected, a 25th percentile score from those sites was selected as the cutoff for "good" and "marginally impaired". The results for EPT Taxa Richness showed that in riffles the 25th percentile value was 17 and, in pools, it was 6. Figure 4-6 shows the cumulative distribution of the reference site and all sites for the EPT Taxa Index and the derivation of the good and marginally impaired threshold.

The following criteria for stream condition based upon the EPT Taxa Index were set:

	Riffles	Pools
Good	>= 17	>= 6
Marginal	9-16	3-5
Poor	0-8	0-2

5.0 Physical Habitat

Physical habitat in streams includes all those physical attributes that influence organisms within the stream. Stream physical habitat varies naturally, as do biological characteristics; thus, expectations differ even in the absence of anthropogenic disturbance. Within a given physiographic-climatic region, stream drainage area and overall stream gradient are likely to be strong natural determinants of many aspects of stream habitat. This is due to their influence on discharge, flood stage, and stream power (the product of discharge multiplied by gradient). Summarizing the results of a workshop conducted by EMAP on stream monitoring design, Kaufmann (1993) identified seven general physical habitat attributes important in influencing stream ecology:

Channel Dimensions
Channel Gradient
Channel Substrate Size and Type
Habitat Complexity and Cover
Riparian Vegetation Cover and Structure
Anthropogenic Alterations
Channel-Riparian Interaction

All of these attributes may be directly or indirectly altered by anthropogenic activities. Nevertheless, their expected values tend to vary systematically with stream size (drainage area) and overall gradient (as measured from topographic maps). The relationships of specific physical habitat measurements described in this section to these seven attributes are discussed by Kaufmann (1993). Aquatic macrophytes, riparian vegetation, and large woody debris are included in physical habitat assessments because of their role in modifying habitat structure and light inputs, even though they are actually biological measures.

5.1 Data Collection

The procedures were employed on a sampling reach length 40 times its low flow wetted width, as described earlier in Section 2. Measurement points were systematically placed to statistically represent the entire reach. Stream depth and wetted width were measured at very tightly spaced intervals, whereas channel cross-section profiles, substrate, bank characteristics and riparian vegetation structure were measured at larger spacings. Woody debris was tallied along the full length of the sampling reach, and discharge was measured at one location. The tightly spaced depth and width measures allowed calculation of indices of channel structural complexity, objective classification of channel units such as pools, and quantification of residual pool area, pool volume, and total stream volume.

There are five different components of the EMAP physical habitat characterization, including stream discharge. The *thalweg profile* is a longitudinal survey of depth, habitat class, and presence of soft/small sediment at 100 equally spaced intervals (150 in streams less than 2.5 m wide) along the centerline between the two ends of the sampling reach. “Thalweg” refers to the flow path of the deepest water in a stream channel. Wetted width was measured at 21 equally spaced intervals. Data for the second component, the *woody debris tally*, were recorded for each of 10 segments of stream located between the 11 transects. The third component, the *channel and riparian characterization*, includes measures and/or visual estimates of channel dimensions, sinuosity, and morphometric complexity.

Stream Discharge: Stream discharge is equal to the product of the mean current velocity and vertical cross sectional area of flowing water. Discharge measurements are critical for assessing trends in streamwater acidity and other characteristics that are very sensitive to streamflow differences. Discharge was measured at a suitable location within the sample reach that was as close as possible to the location where chemical samples were collected (typically the X-site as described in Section 2). No single method for measuring discharge was applicable to all types of stream channels. The preferred procedure for obtaining discharge data was based on "velocity-area" methods (e.g., Rantz 1982; Lindsley et al. 1982). For streams that were too small or too shallow to use the equipment required for the velocity-area procedure, two alternative procedures were employed. One procedure is based on timing the filling of a volume of water in a calibrated bucket. The second procedure is based on timing the movement of a neutrally buoyant object (e.g., an orange) through a measured length of the channel, after measuring one or more cross-sectional depth profiles within that length.

Thalweg Profile: The thalweg profile is a longitudinal survey of maximum depth and several other selected characteristics at 100 or 150 equally spaced points along the centerline of the stream between the two ends of the stream reach. Data from the thalweg profile allowed calculation of indices of residual pool volume, stream size, channel complexity, and the relative proportions of habitat types such as riffles and pools.

Large Woody Debris Tally: Methods for large woody debris (LWD) measurement was a simplified adaptation of those described by Robison and Beschta (1990). This component of the EMAP physical habitat characterization allowed quantitative estimates of the number, size, total volume and distribution of wood within the stream reach. LWD was defined here as woody material with a small end diameter of at least 10 cm (4 inches) and a length of at least 1.5 m (5 ft). Generally, the extent of large woody debris is directly related to the extent of habitat complexity through development of obstructions and diversions within the stream flow.

Slope and Bearing: The slope, or gradient, of the stream reach is useful in three different ways. First, the overall stream gradient is one of the major stream classification variables, giving an indication of potential water velocities and stream power, which are in turn important controls on aquatic habitat and sediment transport within the reach. Second, the spatial variability of stream gradient is a measure of habitat complexity, as reflected in the diversity of water velocities and sediment sizes within the stream reach. Lastly, using methods described by Stack (1989) and Robison and Kaufmann (1994), the water surface slope allowed the computation of residual pool depths and volumes from the multiple depth and width measurements taken in the thalweg profile. Compass bearings between cross section stations, along with the distance between stations, allowed the estimation of the sinuosity of the channel (ratio of the length of the reach divided by the straight line distance between the two reach ends).

Substrate Size and Channel Dimensions: Substrate size is one of the most important determinants of habitat character for fish and macroinvertebrates in streams. Stream bottom characteristics are often cited as major controls on the species composition of macroinvertebrate, periphyton, and fish assemblages in streams (e.g., Hynes 1972; Cummins 1974; Platts et al. 1983). Along with bedform (e.g., riffles and pools), substrate character influences the hydraulic roughness and consequently the range of water velocities in the channel. It also influences the size range of interstices that provide living space and cover for macroinvertebrates, salamanders, and sculpins. Substrate characteristics are often sensitive indicators of the effects of human activities on streams (MacDonald et al. 1991). Decreases in the mean substrate size and increases in the percentage of fine sediments, for example, may destabilize channels and indicate changes in the rates of upland erosion and sediment supply (Dietrich et al. 1989; Wilcock 998). Consequently, changes in substrate size distributions are often indicative of catchment and streamside disturbances that alter hillslope erosion or mobilize sediment. Accumulations of fine substrate particles also fill the interstices of coarser bed materials, reducing habitat space and its availability for benthic fish and macroinvertebrates (Platts et al. 1983; Hawkins et al. 1983; Rinne 1988). In addition, circulation of well-oxygenated water is impeded when fine particles embed coarser, more permeable substrates. Most practitioners (e.g., Platts et al. 1983; Bauer and Burton 1993), including the EMAP field protocols (Kaufmann and Robison 1998) employ a systematic "pebble count," as described by Wolman (1954), to quantify the substrate size distribution, with visual assessments of substrate embeddedness as described by Platts et al. (1983). Substrate size and embeddedness were evaluated at each of the 11 cross-section transects using a combination of methods adapted from those described by Wolman (1954), Bain et al. (1985), Platts et al. (1983), and Plafkin et al. (1989).

Bank Characteristics: Bank and channel dimension measurements included bank angle and bank undercut distance determined on the left and right banks at each cross section transect. Other features that were measured included the wetted width of the channel, the width of exposed mid-channel bars of gravel or sand, estimated incision height, and the estimated height and width of the channel at bankfull stage. The "bankfull" or "active" channel was defined as the channel that is filled by moderate-sized flood events that typically occur every one or two years. Such flows do not generally overtop the channel banks to inundate the valley floodplain, and are believed to control channel dimensions in most streams.

Canopy Cover Measurements: The importance of riparian vegetation to channel structure, cover, shading, nutrient inputs, large woody debris, wildlife corridors, and as a buffer against anthropogenic perturbations is well recognized (Naiman et al. 1988; Gregory et al. 1991). Riparian canopy cover over a stream is important not only in its role in moderating stream temperatures through shading, but also as an indicator of conditions that control bank stability and the potential for inputs of coarse and fine particulate organic material (MacDonald et al. 1991). Organic inputs from riparian vegetation become food for stream organisms and structure to create and maintain complex channel habitat. Canopy cover over the stream is determined at each of the 11 cross-section transects. A Convex Spherical Densiometer (model B) was used (Lemmon 1957).

Riparian Vegetation Structure: Visual estimation procedures were used to supplement previous measurements with a semi-quantitative evaluation of the type and amount of various types of riparian vegetation. These data were used to evaluate the health and level of disturbance of the stream corridor. They also provide an indication of the present and future potential for various types of organic inputs and shading. Observations to assess riparian vegetation apply to the riparian area upstream 5 m and downstream 5 m from each of the 11 cross-section transects. They included the visible area from the stream back a distance of 10 m (30 ft) shoreward from both the left and right banks, creating a 10 m × 10 m riparian plot on each side of the stream. The riparian plot dimensions were estimated, not measured. Riparian vegetation structure was measured by visual estimates of the areal cover and type of vegetation in three layers (canopy, mid-layer, and ground cover), distinguishing evergreen from deciduous vegetation, and woody trees and shrubs from herbaceous vegetation.

Instream Fish Cover, Algae, and Aquatic Macrophytes: This portion of the EMAP physical habitat protocol was a visual estimation procedure that semi-quantitatively evaluated the type and amount of important types of cover for fish and macroinvertebrates. Alone and in combination with other metrics, this information was used to assess habitat complexity, fish cover, and channel disturbance. Estimates were made of the areal cover of all of the fish cover and other features that were in the water and on the banks 5 m upstream and downstream of the cross-section. The areal cover classes of fish concealment and other features were the same as those described for riparian vegetation.

Human Influence: The field evaluation of the presence and proximity of various important types of human land use activities in the stream riparian area was used in combination with mapped watershed land use information to assess the potential degree of disturbance of the sample stream reaches. For the left and right banks at each of the 11 detailed Channel and Riparian Cross-Sections, the presence/absence and the proximity of 11 categories of human influences was evaluated. This assessment included the frequency and extent of both in-channel and near-channel human activities and disturbances. In-channel disturbances include channel revetment, pipes, straightening, bridges, culverts, and trash (e.g., car bodies, grocery carts, pavement blocks, etc.). Near-channel riparian disturbances include buildings, lawns, roads, pastures, orchards, and row crops. The observations and proximity evaluations were related to the stream and riparian area within 5 m upstream and 5 m downstream from the station.

5.2 Metric Selection and Testing

Eighteen metrics from the measurement suite described in Section 5.1 were selected for inclusion in seven separate indices that describe physical habitat condition in the MAHA streams report. These indices and composite metrics are defined in Section 5.3. The metrics selected are derived from channel morphology, substrate, fish cover, riparian vegetation, riparian human disturbance, pool habitat, and riparian canopy cover features as found in Kaufmann et al. (1999).

For each metric, an analysis of variance (ANOVA) model was used to estimate variances among streams, the signal, and those associated with repeat visits in the same year, which is referred to here as measurement noise. The latter variance estimate includes measurement error, and combined effects of within season habitat variation, information collection by separate field crews, and ability to relocate revisit samples. Three tests of precision were employed: a measure of the repeat visit variance, i.e., residual mean square error in the ANOVA model; the coefficient of variation (CV), i.e., repeat visit variance divided by the grand mean across sites as percent; and the signal to noise ratio which is the ratio of the metric variance across the entire region to the repeat visit metric variance. Precision of a metric will increase as repeat visit variance and CV decrease and the signal to noise ratio increases. The higher the S/N ratio is for a metric, the more that metric is able to discern changes in single or multiple sites. The number of streams evaluated and number of repeat visit data used in the analysis were 169 and 50, respectively.

The metrics selected for inclusion in the seven habitat indices and results of precision testing of 15 physical habitat variables are presented in Table 5-1. Precision testing for the following three metrics were unavailable:

- Percent of substrate as concrete (PCT_RC)
- Bed Stability (LRBS_BW4)
- Mean Bed Shear Stress Index (LDMB_BW4)

Table 5-1. Precision of Physical Habitat Metrics in the Mid-Atlantic region (N=169 streams with 50 repeat visits in 1993-1994), (after Kaufmann et al. 1999).

Physical Habitat Metrics	Revisit Var.	CV (%)	Signal/ Noise
Thalweg mean depth, cm (XDEPTH)	6.4	22	7.3
Thalweg depth standard deviation, cm (SDDEPTH)	1.7	13	16
Mean residual depth, cm (RP100)	1.6	17	16
Mean channel gradient, % (XSLOPE)	0.8	42	18
Substrate 16mm diameter, % (PCT_SFGF)	7.5	17	11
Embedded substrate of midchannel and margin, % (XEMBED)	15	27	1.9
Areal cover of filamentous algae, proportion (XFC_ALG)*	0.067	224	0.08
Areal cover aquatic macrophytes, proportion (XFC_AQM)*	0.031	102	4.7
Areal cover large woody debris, proportion (XFC_LWD)	0.040	142	0.2
Areal cover of all types summed, proportion (XFC_ALL)	0.22	46	0.8
Canopy cover at bank by densitometer, % (XCDENBK)	8.0	10	7.3
Woody vegetation cover in three layers, proportion (XCMGW)	0.25	28	2.3
Riparian human disturbance from pipes (W1_PIPE)	0.03	162	3.4
Riparian human disturbance from channel revetment (W1_WALL)	0.02	20	185
Riparian Human Disturbance Index (W1_HALL)	0.51	41	3.3

** The percent (%) values of these metrics were used in index computation.*

5.3 Index Calculations

5.3.1 Index of Riparian Habitat Condition

The importance of riparian vegetation to channel structure, cover, shading, nutrient inputs, large woody debris, wildlife corridors, and as a buffer against anthropogenic perturbations is well recognized (Naiman et al. 1988; Gregory et al. 1991). Riparian canopy cover over a stream is important not only for its role in moderating stream temperatures through shading, but also as an indicator of conditions that control bank stability and the potential for inputs of coarse and fine particulate organic material (MacDonald et al. 1991). Organic inputs from riparian vegetation become food for stream organisms and provide structure that creates and maintains complex channel habitat. Land use, buildings, and other evidence of human activities in the stream channel and its riparian zone may, in themselves, serve as habitat quality indicators; they may also serve as diagnostic indicators of anthropogenic stress. The EMAP wadeable stream field methods (Kaufmann and Robinson 1998) evaluate channel shading (using canopy densimeter measurements) and riparian vegetation structure by visual estimates of the areal cover and type of vegetation in three layers (canopy, mid-layer, and ground cover), distinguishing evergreen from deciduous vegetation, and woody trees and shrubs from herbaceous vegetation. They assess the frequency and extent of both in-channel and near-channel human activities and disturbances. In-channel disturbances include channel revetment, pipes, straightening, bridges, culverts, and trash (e.g., car bodies, grocery carts, pavement blocks, etc.). Near-channel riparian disturbances include buildings, lawns, roads, pastures, orchards, and row crops.

Aspects of riparian vegetation cover, riparian vegetation structural complexity, and the intensity of human disturbances were incorporated into the index of Riparian Habitat Quality used in the MAHA State of Streams. Based on historic literature and the judgment of experts, the "pre-Columbian" reference condition for riparian vegetation in the Mid-Atlantic Highlands was assumed to be a multi-storied corridor of woody vegetation (XCMGW approaching 2.0), with bankside canopy density (XCDENBK) generally complete (85%-100%) along wadeable streams. The reference condition was assumed to lack the types of riparian human activities identified by the EMAP Physical Habitat field methods, which are typical of an agro-industrial society. Kaufmann et al. (1999) calculate the proximity-weighted sum of human activities in the stream and riparian corridor as the variable W1_HALL. To express the combined Riparian Habitat Quality imparted by Riparian vegetation, the variables XCMGW, XCDENBK, and W1_HALL were scaled from 0 (poor quality) to 1.0 (excellent quality) and combined by multiplication, and application of the cube-root of the product to avoid extreme skewness in the resultant index (termed QWR1). A riparian habitat quality index value <0.50 denotes "Poor" condition, >0.50 to <0.63 "Marginal" condition, and values >0.63 indicate "Good" riparian condition.

5.3.2 Channel Sedimentation Index

Stream bottom characteristics are often cited as major controls on the species composition of macroinvertebrate, periphyton, and fish assemblages in streams (e.g., Hynes 1972; Cummins 1974; Platts et al. 1983). Along with bedform (e.g., riffles and pools), substrate size influences the hydraulic roughness and consequently the range of water velocities in a stream channel. It also influences the size range of interstices that provide living space and cover for macroinvertebrates, salamanders, sculpins, and darters. Substrate characteristics are often sensitive indicators of the effects of human activities on streams (MacDonald et al. 1991). Decreases in the mean substrate size and increases in the percentage of fine sediments, for example, may destabilize channels and indicate changes in the rates of upland erosion and sediment supply (Dietrich et al. 1989). Consequently, changes in substrate size distributions are often indicative of catchment and streamside disturbances that alter hillslope erosion or mobilize sediment. Accumulations of fine substrate particles also fill the interstices of coarser bed materials, reducing habitat space and its availability for benthic fish and macroinvertebrates (Platts et al. 1983; Hawkins et al. 1983; Rinne 1988). In addition, circulation of well-oxygenated water is impeded when fine particles embed coarser, more permeable substrates. Most practitioners (e.g., Platts et al. 1983; Bauer and Burton 1993), including the EMAP field protocols (Kaufmann and Robinson 1998) employ a systematic "pebble count," as described by Wolman (1954), to quantify the substrate size distribution, with visual assessments of substrate embeddedness as described by Platts et al. (1983).

Stream bed substrate size distributions and their percentage of fine particles vary naturally among streams of different sizes, slopes, and natural rates of upslope erosion. For the MAHA State of Streams Stream Sedimentation assessment, substrate reference condition assumptions are based on Section 3.2.7 of Kaufmann et al. (1999). Stream sedimentation was defined as an increase or excess in the amount of fine substrate particles relative to an expected reference value that is based on the region and the sediment transport capability (bankfull streambed shear stress) of each sample stream reach. Bankfull streambed shear stress was estimated in this case by the variable LDMB_BW4 (see discussion in Kaufmann et al. 1999), which incorporates physical habitat data on channel slope, bankfull dimensions, large woody debris, and channel cross-section irregularities. Stream channels undergo a long-term adjustment to a region-specific rate of sediment supply delivered by erosion processes under a natural disturbance regime. The size distribution of streambed particles is dependent upon the relationship between sediment supply and stream sediment transport capability. We hypothesize that, given a natural disturbance regime, sediment supply in watersheds not altered by human disturbances may be roughly in long-term equilibrium with stream sediment transport. The relationship between bed particle size and stream transport capability in streams draining watersheds relatively undisturbed by humans should tend toward a characteristic value typical to the region. The largest positive deviations in the amount of fine substrate from predicted values were assumed to be in streams with high sediment input rates, and these augmented rates are generally related to disturbance from human activities. This is born out from relating values of observed/expected substrate diameter to watershed disturbances (see Kaufmann et al. 1999).

In the MAHA State of Streams Sedimentation assessment, predicted values were approximated by regressing PCT_SFGF (i.e., % substrate smaller than 16 mm diameter) on a measure of stream bed shear stress (LDMB_BW4). This procedure yields a range of deviation values above and below the regional mean, which includes contributions from streams over a wide range of disturbance. The lowest residuals (i.e., negative residuals) from the prediction equation are from streams that do not have an excessive amount of fine particles relative to expectations, and tend to be relatively undisturbed streams. Those with the highest residuals are those streams with excess sedimentation, and these tend to drain basins with relatively intensive and extensive human activities.

Values of excess fines percentage were established in the following manner. Streams with a PCT_SFGF at least 10% below the predicted value were rated to be in "Good" condition relative to the sedimentation criteria. Those with PCT_SFGF 10% below to 20% above the predicted value were rated "Marginal". Those with PCT_SFGF more than 20% above regional mean expectations were rated "Poor".

5.3.3 Fish Cover from Large Woody Debris

This metric is the mean areal percent cover in the stream channel that is provided by woody debris with diameter >0.3 m, as estimated by field crews. The variable name used here was XFC_LWD as described by Kaufmann et al. (1999).

5.3.4 Channel and Riparian Disturbance Index

This disturbance index is a proximity-weighted index of the extent and intensity of human activities within the channel, riparian, and near the riparian, as visible to field crews working at the sample stream reach. The index is calculated as the proximity-weighted sum of 11 categories of human disturbances, including buildings, roads, mining activities, lawns and parks, pastures and grazing, row crops, dams and bank revetments, influent and effluent pipes, trash and landfills, land clearing, and silvicultural activities. It is referred to by the variable name W1_HALL in Kaufmann et al. (1999).

5.3.5 Watershed Quality Index

This is an integrated index that combines information on the land cover, land use, road density, and human population density in the contributing drainage area upstream from each sample stream reach. The measure of natural land cover is the sum of percent areal cover of “non-human” land cover (Forest + wetland + rock outcrop + open water from LUDA Land cover/Land use GIS coverage). Human disturbance information includes LUDA GIS cover for % Urban Land use, % Agricultural Land use, and % Mining Land use. Road density is from “TIGER” GIS data, and human population density is from the U.S. Census Bureau. Each land cover, land use type is given a separate modeled response shape describing the relative contribution (or degradation) to watershed quality as the percentage of the land cover/land use type increases incrementally from zero to 100%, or the density of roads or human population increase from zero to high values. The variable name used in the streams assessment was QW1.

5.3.6 Watershed, Riparian, and Channel Habitat Complexity Index

This index, denoted as variable QWRC2, also is an integrated measure that combines the index of in-channel habitat quality (QCPH2) with the same watershed and riparian quality measures for Watershed Quality and Riparian Habitat Condition Indices described above. The in-channel measures exclude habitat volume indicators, but include measures of five major aspects of channel habitat quality (the variable names below are from Kaufmann et al. 1999):

Velocity and Stream Power:
- Mean channel slope (XSLOPE)
- Mean bed shear stress index (LDMB_BW4)

Substrate Quality:
- % embedded substrate (XEMBED)
- % substrate <16mm diameter (PCT_SFGF)
- % filamentous algae cover (PCT_ALG)
- % aquatic macrophyte cover (PCT_AQM)

Channel Alteration:
- % substrate concrete (PCT_RC)
- % revetted banks (W1_WALL)
- % of channel stops with influent or effluent pipes (W1_PIPE)
- Bed Stability, measured as a deviation of substrate mean diameter from that predicted from channel hydraulics (LRBS_BW4)
- Deviation of residual pool depth (RP100) from that predicted from watershed area and channel slope

Channel Spatial Complexity:
• Coefficient of Variation in Thalweg depth [100(SDDEPTH/XDEPTH)]

Cover for Fish:
• Sum of cover from all types of concealment features (boulders/ledges, undercuts, LWD, brush, overhanging vegetation, and artificial structures (XFC_ALL)
• Cover diversity (number of different types of cover) — so far applied only in Reg 7
Cover from brush + overhanging vegetation (XFC_BRS + XFC_OHV)
• Cover from rock-related elements (XFC_RCK)
• Undercut bank cover (XFC_UCB)
• Large woody debris cover (XFC_LWD)

5.3.7 Channel Habitat Quality

This index also is an integrated measure of in-channel physical habitat quality that excludes habitat volume indicators, but includes measures of five major aspects of channel habitat quality: Velocity and Stream Power, Substrate Quality, Channel Alteration, Channel Spatial Complexity, and Cover for Fish. The variables used to quantify these five aspects of channel habitat quality are described above, as they contribute to the channel portion of the Watershed, Riparian, and Channel Habitat Complexity Index QWRC2. It is referred to by the variable name QCPH2.

6.0 Rapid Habitat and Visual Stream Assessment (EPA RBP)

6.1 Data Collection

This habitat assessment protocol was adapted from EPA's "rapid" bioassessment protocols (Plafkin et al. 1989; Barbour et al. 1999), and has been refined from various applications across the country. The approach focuses on integrating information from specific parameters on the structure of the physical habitat. The objective of the visual stream assessment is to record field team observations of catchment and stream characteristics that are useful for data validation, future data interpretation, ecological value assessment, development of associations, and verification of stressor data. The observations and impressions of field teams are extremely valuable.

Each stream was classified as either "Riffle/run" or "Pool/glide" prevalent based on visual impression of the dominant habitat type. For each prevalent habitat type, twelve characteristics of habitat were considered and evaluated as part of the rapid habitat assessment. These parameters include: instream fish cover; benthic invertebrate epifaunal substrate; embeddedness; velocity and depth regimes; channel alteration; sediment deposition; frequency of riffles; channel flow status; condition of banks; bank vegetative protection; grazing or disruptive pressure; and riparian vegetated zone.

Most of the parameters were evaluated similarly for both types of prevalent habitats. In four cases, the same parameter was evaluated differently, or a different (but ecologically equivalent) parameter was evaluated in riffle/run prevalent versus pool/glide prevalent streams. Epifaunal substrates were evaluated differently in riffle/run and pool/glide prevalent streams. Substrate embeddedness was evaluated in riffle/run prevalent streams, while pool substrate composition was evaluated in pool/glide prevalent streams. The presence of four potential types of microhabitat types based on combinations of depth and current velocity was evaluated in riffle/run prevalent streams, while the presence of four potential types of pool microhabitat based on depth and area were evaluated in pool/glide prevalent streams. The frequency of riffles was evaluated in riffle/run prevalent streams, while channel sinuosity was evaluated in pool/glide prevalent streams.

6.2 Metric Selection and Testing

As discussed in above, data were collected on 12 visual habitat metrics. These parameters include the following:

instream fish cover
benthic invertebrate epifaunal substrate
embeddedness (or pool substrate characterization)
velocity and depth regimes (or pool variability)
channel alteration
sediment deposition
frequency of riffles (or channel sinuosity)
channel flow status
condition of banks
bank vegetative protection
grazing or disruptive pressure
riparian vegetated zone

(Note that pools and riffles were evaluated slightly differently.)

Each of these channel and riparian habitat metrics were scored by the field surveyors from poor (score = 0) to excellent (score = 20).

The ANOVA model described above was again used by Kaufmann et al. (1999) to estimate the precision of the RBP habitat metrics using the residual variance associated with repeat visits, the Coefficient of Variation of that variance, and the signal to noise ratio. The precision test data for the 12 RBP metrics are shown in Table 6-1 for a total of 459 stream samples with 36 repeat visits in the years 1993-1994.

Subcomponent metric repeat variance values ranged from 2.0 to 4.3 points (out of 20) and the CVs ranged from 12 to 30%. Signal to noise ratio ranged from 0 to 4.2. There was general agreement among metrics in all three values. Higher precision was associated with channel alteration, sediment deposition, riffle frequency, bank condition, and grazing (or "other pressures") metrics. Lower precision was exhibited by the instream cover, epifaunal substrate embeddedness, and bank vegetation metrics. The highest S/N ratio was found with riparian vegetative zone width, which had moderate values for the other two precision estimates.

Table 6-1. Precision of Rapid Bioassessment Protocol (RBP) habitat quality metrics in Mid-Atlantic region (N=459 streams with 36 repeat visits in 1993-1994) [after Kaufmann et al. 1999].

RBP Habitat Metrics	Revisit Var.	CV (%)	Signal/Noise
Instream Cover (Fish)	3.7	28	0.7
Epifaunal Substrate	4.3	30	0
Embeddeness (or Pool Substrate*)	3.6	28	0.6
Velocity/Depth Regime (or Pool Variability*)	3.2	25	0.9
Channel Alteration	2.0	12	2.0
Sediment Deposition	2.5	19	2.5
Riffle Frequency (or Channel Sinuosity*)	2.8	18	1.1
Channel Flow Status	3.2	22	0.8
Bank Condition	2.5	18	1.8
Bank Vegetative Protection	3.7	25	0.4
Grazing or Other Disruptive Pressure	2.3	15	3.3
Riparian Vegetative Zone Width	2.9	24	4.2
RBP Habitat Quality Total Score	23	14	1.6

** Repeat visits were not made to measure these low gradient stream habitat assessment features.*

It should be noted that, in general, S/N ratios were substantially lower that those described for most of the fish metrics. The RBP metrics associated with flow-related parameters are expected to exhibit the greatest variability. Some of these do have the lower S/N ratios.

6.3 Index Calculation and Testing

The RBP Habitat Quality score is based upon the sum of the individual 12 metric score of 0-20, which when summed can have a total score of 240. Tests of its precision also are found in Table 6-1. With repeat variance and CV values of 23 and 14%, respectively, Kaufmann et al. (1999) conclude that these values are relatively small compared to the potential range of variation and the overall mean. They also found that the RBP indicate a good potential to identify among-stream variation and change in habitat quality over time. However, it also was observed that the low S/N ratio of 1.6 is indicative of either a true lack of variation in habitat quality among streams or a failure of the RBP metric to be responsive to habitat quality variation.

7.0 Watershed Disturbance

MAHA stream condition was evaluated by two independent measures of watershed disturbance. The first was the Watershed Risk Index developed by Bryce et al. (1999) that classified streams into five condition classes. A second measure defined as the Watershed Disturbance Index (Burch-Johnson, in preparation) classified streams into good, fair, and poor categories. These indices and associated metrics are described below.

7.1 Watershed Risk Index

A watershed disturbance risk index was developed by Bryce et al. (1999) that incorporates landscape features at the watershed level in order to identify the human activities that pose risks to stream ecosystems. This index was used to evaluate 102 stream reaches and their watersheds that were otherwise sampled in the MAHA program in 1993 and 1994. The watersheds were stratified by ecoregion and respective reference conditions that was defined as those sites minimally altered by human activity. In general, these conditions were most often associated with mature second growth forests with roads absent from the riparian zone and minimal human activity in the watershed.

7.1.1 Watershed Disturbance Metrics

Three types of information were evaluated to identify metrics to be used in the risk index computation. Watershed physical characteristics, population distributions, and farm/forest land use estimates were made from U.S. Geological Survey 1:24,000 topographic maps. Aerial photographs taken from 1989 to 1993 at 1:40,000 scale by the National Aerial Photography Program (USDA-ASCS) were used to update USGS maps and provide more detail on land use and land cover. Site visit data were reviewed to provide stream reach physical habitat and riparian zone information. All identifiable human alterations were recorded, particularly as they would influence vegetative cover, channel morphology, sedimentation, and chemical loading. Some of the predominant human activities included agriculture, silviculture, mining, urban and residential development, and stream channelization. Table 7-1 lists the information obtained from each of the noted sources.

7.1.2 Index Computation

Regional, watershed, and stream reach scale information gathered as noted in Table 7-1 were consolidated into a stressor matrix for each of the 102 reach sites. Ecoregional factors related to local climate, lithology, soil erodibility, stream density, and runoff were considered in developing expectations relative to streamside and upland uses. Individual components of the stressor matrix were assigned a weight of +, 0, or — depending on whether that condition preserved "naturalness", had a neutral effect, or was detrimental to naturalness, respectively. Not all stressors were applied to each site; therefore the stressor matrix for each site was somewhat unique. A risk index score of 1 to 5 was assigned to characterize the range of risk from minimal to highest risk of impairment. Table 7-2 offers an example of how six streams were scored using the stressor matrix.

Table 7-1. Types of information obtained from data sources for incorporation in a Watershed Disturbance Risk Index (Bryce et al. 1999).

Topographic Maps (1:24,000)	Aerial Photographs (1:40,000)	Field Visit Information (1993-1994)
Regional location	Update % cleared	Riparian age class
Watershed size	New development	Canopy structure
Elevation	Logging pattern	Shoreline habitat complexity
Drainage pattern	Riparian vegetation pattern	Woody debris
Wetland areas	Relative forest age class	Shoreline development
Population pattern	Rowcrop agriculture	Farm type
Relative area cleared	Grazing (estimated)	Visible point sources
Mines, gravel pits	Feedlots	Visible recreation pressure
Oil and gas wells	Reclaimed mines	Presence of aquatic vegetation
Road density	Channelization	Substrate types
Powerline corridors		Sedimentation
Protected areas		Impressions of biodiversity
Public land		Aesthetic appeal
		Anecdotal information

Watersheds that were generally forested with low road and residential densities received a score of 1 or 2. A watershed with these characteristics would receive a 2 score due to a number of disqualifying factors, such as a road paralleling a stream or presence of sedimentation. The highest risk score of 5 was reserved for those sites that exhibited a majority of conditions thought to negatively impact stream condition. The presence of mitigating factors, such as mine reclamation, would lower that score to the 4 category. The final score integrated quantifiable aspects of watershed condition with qualitative interpretations of degree of impact. The repeatability of the scoring process was evaluated by Bryce et al. (1999) with the result that two individuals scored 12 of the 13 evaluated watersheds alike.

Table 7-2. Stressor matrix showing criteria and progression of risk index scores for six sites in the Ridge and Valley ecoregion (Bryce et al. 1999).

STREAM ID RISK ATTRIBUTES	WT.	WV754	PA756	MD772	WV756	PA522	PA532
Protected area or trail access	+	X					
Completely forested	+	X					
Low instream sediment (0-30% area)	+	X	X	X			
Complex instream fish habitat (>40% est. area of 10m w. trans.)	+	X	X				
Large riparian trees (>0.3 dbh)	+	X	X	X			
Few residences upland or streamside	+		X	X			
Mostly forested (<30% cleared)	**0**		X				
>18m forested riparian zone	**0**		X	X			
Moderate streamside residential	**0**				X		
Road density 5-15m/ha	**0**		X	X	X		
Road parallels stream	**0**		X		X		X
Watershed cleared (30-60%), moderate agriculture and logging	**0**			X	X		
Moderate sediment (30-50% area affected)	**0**				X		X
Trash, odor, surface film present	**-**			X	X	X	X
High watershed cleared (>60%)	**-**					X	X
Near stream agriculture, grazing, and logging	**-**			X	X	X	X
High bank erosion (50-60%)	**-**			X			
Little instream fish habitat (<10% est. area of 10m wide trans.)	**-**					X	
Road density >15 m/ha	**-**					X	X
High sediment (>50% area affected)	**-**					X	
Minimal riparian buffer	**-**				X	X	X
High streamside industrial, urban, or rural point source (feedlot)	**-**					X	X
Channelization, dredging, rip-rap present	**-**				X	X	X
Oil and gas wells, pipes	**-**						X
Strip/underground mines, mine drainage	**-**				X		X
RISK INDEX SCORE		1	2	3	4	5	5

7.1.3 Testing of the Watershed Risk Index

The responsiveness of the watershed risk index was evaluated by comparison to chemical factors and benthic macroinvertebrate measures collected synoptically in the same streams. PCA was used to capture nutrient richness (total P, total N, nitrate and ammonia-N) and ionic strength (eight major anions and cations) gradients. The PCA on nutrient richness revealed two axes (PCA I and II) that accounted for 59 and 24% of the variability, respectively. Similarly, two axes of the PCA on ionic strength accounted for 61 and 14% of the variability. In general, the gradient in chemistry values in each ecoregion corresponded with a gradient in risk scores, i.e., higher ionic strength and nutrient richness values were associated with higher risk scores. For example, the first PCA axis for ionic strength shows a linear increase relative to risk index scores; a similar relationship was found in a comparison to chloride content (Figure 7-1).

Comparisons also were made to the biotic stream measures Hilsenhoff Biotic Index (HBI) and % EPT

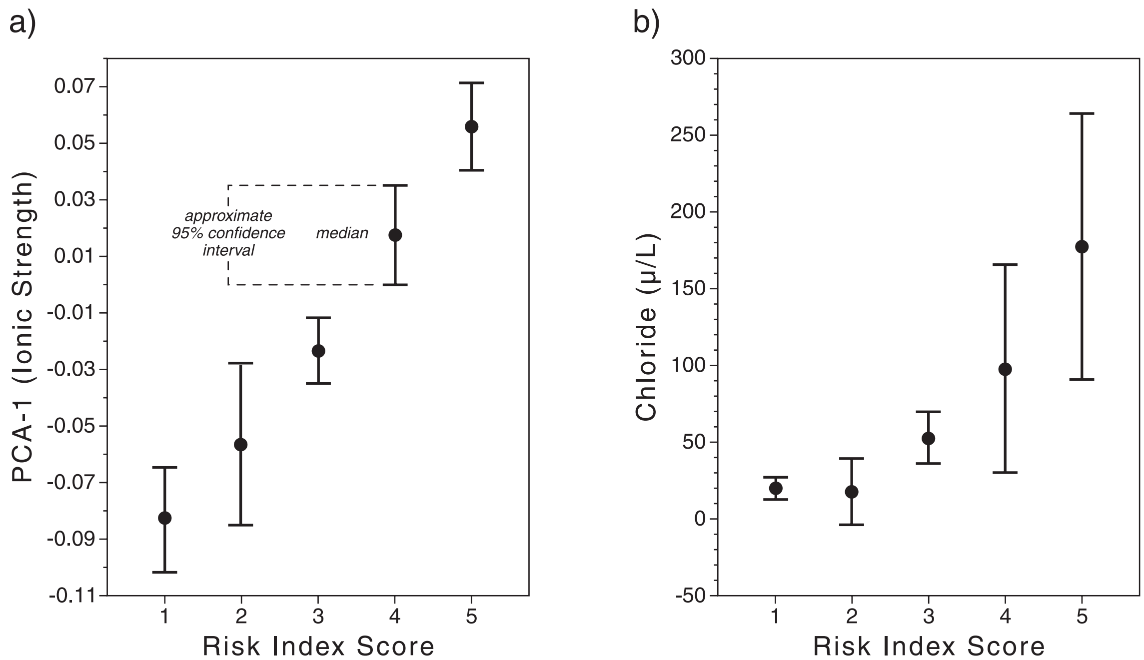

Figure 7-1. Relationship of watershed risk index to ionic strength and chloride.

taxa. Figure 7-2 a and b shows fairly good agreement between improved biotic condition and watershed risk. After adjustment of these two biotic measures for shear stress and elevation by regression analysis, a weaker but identifiable relationship to watershed risk scores still existed, thus indicating that the risk index has the ability to capture anthropogenic effects in spite of corrections for natural variability.

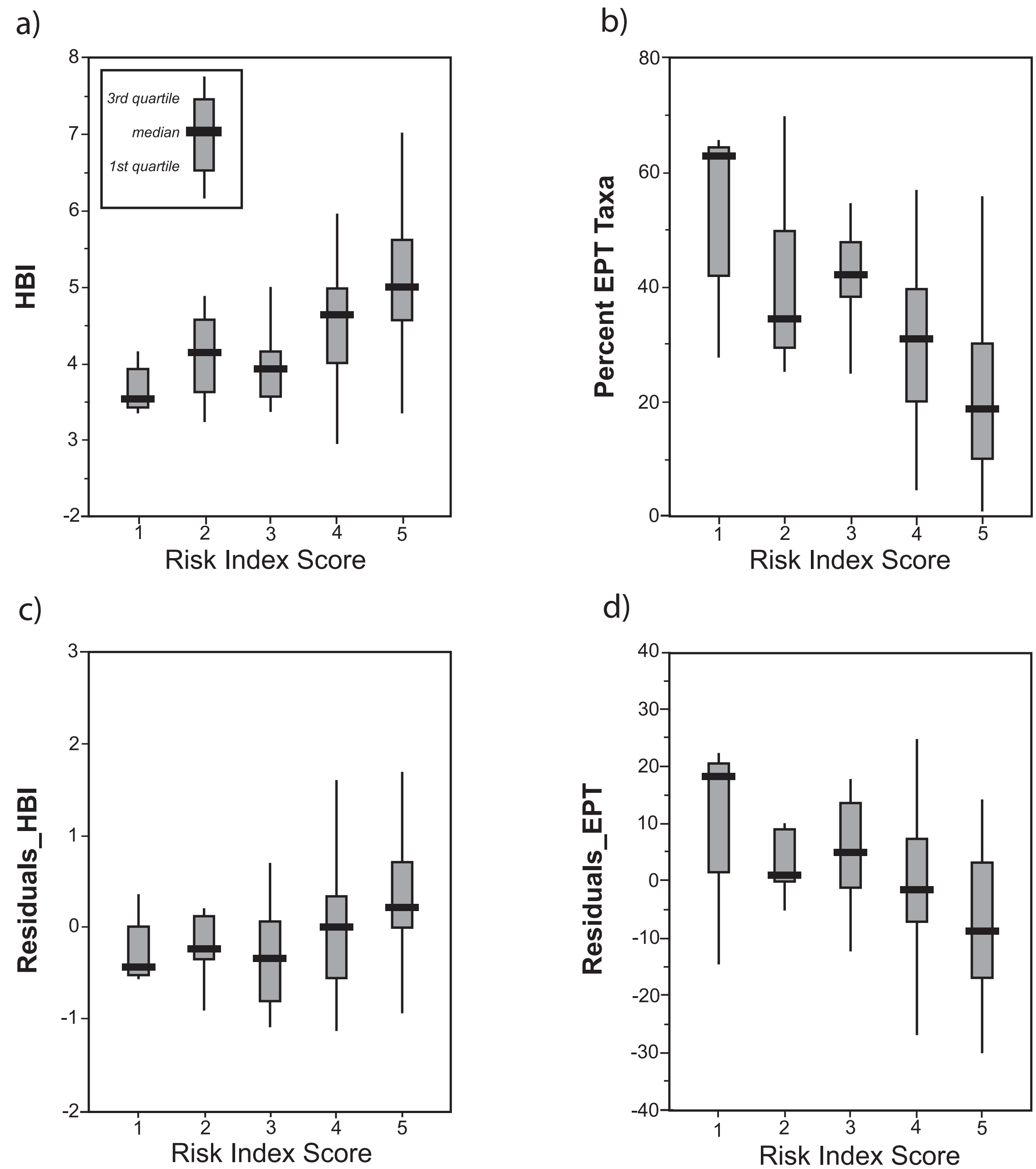

Figure 7-2. Comparison of the watershed risk index to biotic condition with normal score and those adjusted for natural variability.

7.2 Watershed Disturbance Index

Research regarding appropriate thresholds or criteria for classifying individual stream watersheds is continuing. Therefore, this approach should be viewed as the current status in the development process rather than a finished product.

The EMAP-Surface Water classification scheme for these disturbance metrics was deliberately restricted to watershed-level data derived from available sources (i.e., USGS Land Use/Land Cover and Census Bureau data) using GIS techniques. Influences of watershed land use/land cover on aquatic ecosystems have been widely reported in the literature (see Richards et al. 1996; Allan et al. 1997). However, until recently, many investigations focused only on chemical contaminants, nutrient enrichment, a single drainage basin, or one land use type.

7.2.1 Watershed Disturbance Metrics

A wide range of natural and anthropogenic data are available for EMAP watersheds. Principal component analyses (PCA) on Northeast lake data identified forest, urban, and agriculture percentages, human population density, and road density as primary variables for watershed disturbance (Whittier et al. 1997). In the Mid-Atlantic region, forest and agriculture percentages are strongly, inversely related to watershed condition (Burch Johnson et al., in review) therefore, the forest variable was dropped. The percentage of mines/quarries was added to the variable list because mining activities are an important stressor in the Highlands. Threshold values for each variable were determined by literature recommendations, professional judgment, and experimentation. When using EMAP data to determine a cut-off, generally the data were split by sampling year (93-94) and one half were restricted from the development process for later testing. Often the experimental thresholds were first examined against the "condition class" variable developed and documented by Bryce et al. (1999), and then applied to the entire data set.

The EMAP urban percentage criterion for the "poor" category was set progressively lower as more information became available and more experimentation was done. The MDNR used a value of 50% urban as part of the "degraded" criteria. Maxted and Shaver (1996) reported in a study of 38 Delaware watersheds that stormwater management pond facilities did not attenuate the impacts of urbanization once 20% impervious cover was reached. Further, about 90% of the sensitive macroinvertebrates were generally eliminated at 10-15% impervious cover in the watershed. As a "rule of thumb", the runoff coefficient from highly developed urban areas is 0.8 - 0.9, given a particular rainfall amount and land area (Corvallis Public Works Department, personal communication). A rough estimate of the percent urban area was calculated as $U = I/0.8$; where U = urban % and I = impervious surface %. Thus, serious macrobenthos effects occurring at 10-20% imperviousness translates to roughly 12.5-25% urban. Wang et al. (1997) reported a similar threshold of 10-20% urban land use beyond which IBI scores were consistently low for 134 stream sites in Wisconsin. Although these thresholds are a good starting point, they represent areas of higher urbanization than in the Mid-Atlantic region. About 48% of the Delaware project was in urban land while 7% of the Wisconsin watersheds were more than 20% urban (3% urban for entire state). On average, the 368 EMAP-SW stream watersheds were only 1% urban, based on classified thematic mapper data (Herlihy et al. 1998). When using the USGS Land Use/Land Cover (LULC) data, the average for the watersheds was about 2-4% urban. Of course, the percent of urban land varies by ecoregion; ranging from 1.9% to 6.7% urban for the entire "Blue Ridge/Ridge" and "Valley" ecoregions, respectively.

For hydrologic units, the percent of urban land ranges from approximately 3.2% to 4.5%. With these averages as guidelines, the cut-off for the “poor” category was set at 3% urban. In the “good” category, the urban percentage criterion is zero. This does not mean that there is a total absence of “urban” features in the watersheds because scattered residences and narrow commercial/residential developments along roads or lake shorelines may not have met mapping criteria for either TM or LULC.

Mines/quarries comprise only a small portion of the total land cover in all ecoregions (0.2% mines/quarries in the Valleys up to 1.5% in the Northern and Central Appalachians). Few EMAP stream watersheds have substantial amounts of mining (>10% mines). However, mining is a significant aquatic stressor when present in a watershed. The thresholds were set at zero for “good” sites and at the 1994 sample mean of 0.6% for “poor”. Like the urban data, a zero percent mining value does not necessarily imply a complete absence of mines/quarries in the watershed. The age of the LULC data and the difficulty of detecting and mapping subsurface mines from high-altitude imagery may affect the percentages reported. Because mines and quarries are classed together in the database, different effects cannot be distinguished.

The thresholds for agriculture percentage are tentative. In Wisconsin, where 73% of the watersheds studied were >50% agriculture, Wang et al. (1997) detected obvious declines in habitat quality and IBI scores only after agricultural land exceeded 50%. However, some sites with more than 80% agriculture retained good quality and biotic integrity. Bryce et al. (1999) used 30-60% cleared land (agriculture and/or logging) to define “moderate” impacts and >60% cleared for the “highly disturbed” class when ranking 102 Mid-Atlantic watersheds. If calculated by MAHA ecoregions, agriculture ranges from 13% in the Blue Ridge/Ridge region to 57% in the Valleys. The mean agriculture percentage for all 1994 watersheds was approximately 24% while the median was 15%. As a starting point, the agriculture thresholds were set to the median of 15% for the “good” category and 45% for the “poor” class (i.e., 3 times 15%; roughly equal to Wang et al.).

Although the literature frequently identifies roads as a watershed stressor, particularly in terms of chloride in lakes or streams, few investigations try to quantify road density effects. McGurk and Fong (1995) used an “equivalent roaded area” (ERA) index, developed by the USDA Forest Service, to assess the effects of forest management in California’s Sierra Nevada and Klamath mountain ranges. The method does not separate road effects from other disturbances but standardizes management and natural activities (clear-cuts, prescribed burns, wildfires) in terms of equivalent roaded acres based on coefficients. Road cut-and-fill areas have a disturbance coefficient of 1.00 while a tractor clearcut has coefficients of 0.2 - 0.3. Equivalent Roaded Area values less than 5% were not associated with changes in aquatic insect diversity, whereas higher values were associated with declines. Although this index cannot be used directly for MAHA sites due to differences in purpose and road type or usage, it does suggest that thresholds exist and are likely to be low. By sorting the 1994 EMAP data by road density, it appeared that the percent of urban lands and condition classes were higher (indicating more disturbance) above the mean road density of 15 m/ha, thus that became the cut-off for the “poor” class. Road densities between 10 and 15 m/ha were most frequent, so 10 was set as the “good” threshold.

The human population density thresholds were the result of some literature information, statistical distributions, and professional judgment. Because detailed studies of lake water quality often include data on the number, age, and septic systems of dwellings around the lake, it seemed that individual residences are important "stressor" units. Further, each building is mapped on USGS 1:24,000-scale topographic maps when it can be done legibly (USGS 1991). A "locale" is defined as a place at which there is or was relatively minor human occupation or activity (i.e., farm, camp, ghost town, junction, railway station, etc). Populated places are classified by population and labeled using distinctive type sizes. A "compact community" consists of 5-40 houses. According to EMAP watershed population and housing estimates derived from 1990 Census data, the number of persons per household is most often 2-3. Also, the frequency distribution of population density decreases almost exponentially; Q1 = 2.99, median = 8.09, Q3 = 19.26, mean = 32.12, and maximum = 2,625.36. Because the first quartile translates to about one dwelling with average occupancy, the threshold for "good" sites was set to 3. The Q3 and mean values would be roughly equivalent to 6-16 houses, or "compact communities" as defined by USGS mapping standards. Thus, the threshold for "poor" sites was set at 15 to connote a small community in a watershed. These values are not definitive and will likely change when better information becomes available.

7.2.2 Index Computation

The disturbance metrics were used to define classes of increasing anthropogenic disturbance, such that good < marginal < poor. All good criteria must be met (AND) to be classified in good condition and exceedance of any poor (OR) criteria will designate poor condition. Streams not classified as good or poor are in the fair category.

Table 7-3. Thresholds for watershed disturbance metrics classifying streams as in good or poor condition.

Watershed Metric	Good (AND)	Poor (OR)
Urban Land Use (% cover)	0	>3
Mines/Quarries (% cover)	0	>0.6
Agriculture (% cover)	<15	>45
Road Density (m/ha)	<10	>15
Population Density (persons/km^2)	<3	>15

7.2.3 Testing of the Watershed Disturbance Index

The 1993 and 1994 EMAP watersheds were classified using the above criteria. Some preliminary one-way ANOVAs were conducted with the resulting watershed condition variable (wscond) and selected chemical, physical habitat, and macrobenthos metrics. In general, the differences in means were more pronounced for the chemistry variables than for habitat or benthos variables. The relationship with chloride (L_CL) was particularly strong. In many cases, variability was largest for streams in the “poor” category. Most analyses showed significant differences of the means for at least the good and poor classes. The watershed condition variable was calibrated to some of the qualitative condition class values (assigned by Bryce), therefore a strong relationship was expected. However, this step seemed important to make the watershed condition variable a predictive “screening” tool for the sites not yet assigned condition classes and to efficiently identify candidate reference sites.

8.0 Fish Tissue Contaminants

Specimens of fish species that commonly occurred throughout the region of interest, and that were sufficiently abundant within a sampling reach were retained for analysis of fish tissue contaminants. If possible, two types of composite samples of fish were prepared at each site. One composite sample was prepared using individuals of a *Primary Target Specie*s, which included species of fish whose adults are small (e.g., small minnows, sculpins, or darters). The second composite sample was prepared using individuals of a *Secondary Target Specie*s, which were those whose adults are of larger size (e.g., suckers, bass, trout, sunfish, carp).

At the analytical laboratory, the fish were composited, processed, and analyzed by the methods summarized in Table 8-1 for metals, Table 8-2 for pesticides, and Table 8-3 for PCB congeners. Maximum holding times for frozen whole fish have not been established; all EMAP fish tissue samples were analyzed within one year of date of collection.

Table 8-1. Analytical methods for metals analysis in fish.

Analyte (CAS No.)[a]	Detection Limit (ng/g)[b]	Summary of Method	References
Aluminum (7429-90-5)	10	Digestion with hot HNO_3 and H_2O_2. Analysis by graphite furnace atomic emission spectrometry (GFAAS) or inductively coupled plasma (ICP)	EPA 200.3 (rev. 1); EPA 200.11 (EPA, 1991a); McDaniel, 1990; EPA, 1989b; CLP (EPA, 1991b); APHA, 1989; EPA 7000 series (EPA, 1990a)
Arsenic (7440-38-2)	2.0		
Cadmium (7440-43-9)	0.2		
Chromium (7440-47-3)	0.1		
Copper (7440-50-8)	5.0		
Iron (7439-89-6)	50.0		
Lead (7439-92-1)	0.1		
Nickel (7440-02-0)	0.5		
Selenium (7782-49-2)	0.1		
Silver (7440-22-4)	0.01		
Tin (7440-31-5)	0.05		
Zinc (7440-66-6)	50.0		
Mercury (7439-97-6)	0.01	Digestion with hot HNO_3 and H_2O_2. Analysis by cold vapor atomic absorption spectrometry	EPA 200.3 (rev. 1), EPA 245.6 (rev. 1)

[a] *Chemical Abstract Services (CAS) registration number.*
[b] *Units are ng/g fresh tissue weight.*

Table 8-2. Analytical methods for pesticides analysis in fish.

Analyte (CAS No.)[a]	Detection Limit (ng/g)[b]	Summary of Method	References
Aldrin (309-00-2) Chlordane-*cis* (5103-71-9) Chlordane-*trans* (5103-74-2) 2,4'-DDD (53-19-0) 4,4'-DDD (72-54-8) 2,4'-DDE (3424-82-6) 4,4'-DDE (72-55-9) 2,4'-DDT (789-02-6) 4,4'-DDT (50-29-3) Dieldrin (60-57-1) Endosulfan-I (959-98-8) Endosulfan-II (33213-65-9) Endrin (72-20-8) Heptachlor (76-44-8) Heptachlor Epoxide (1024-57-3) Hexachlorobenzene [Gamma-BHC/Lindane] (58-89-9) Mirex (2385-85-5) *trans*-Nonachlor (3765-80-5) *cis*-Nonachlor (5103-73-1) Oxychlordane (27304-13-8)	1	Soxhlet extraction into hexane/methylene chloride; analysis by gas chromatography/ electron capture detection (GC/ECD) recommended	EPA 608 (NOAA, 1988); EPA 682 (NOAA, 1988); CLP (EPA, 1991c)

[a] *Chemical Abstract Services (CAS) registration number.*

[b] *Units are ng/g fresh tissue weight.*

Table 8-3. Analytical methods for PCB congeners analysis in fish.

Analyte (CAS No.)[a]	Detection Limit (ng/g)[b]	Summary of Method	References
2,4-Dichlorobiphenyl #8 (34883-43-7) 2,2',5-Trichlorobiphenyl #18 (37680-65-2) 2,4,4'-Trichlorobiphenyl #28 (7012-37-5) 2,2',5,5'-Tetrachlorobiphenyl #52 (35693-99-3) 2,2',3,5'-Tetrachlorobiphenyl #44 (41464-39-5) 2,3',4,4'-Tetrachlorobiphenyl #66 (32598-10-0) 2,2',4,5,5'-Pentachlorobiphenyl #101 (37680-73-2) 2,3',4,4',5-Pentachlorobiphenyl #118 (31508-00-6) 2,3,3',4,4'-Pentachlorobiphenyl #105 (32598-14-4) 2,2',4,4',5,5'-Hexachlorobiphenyl #153 (35065-27-1) 2,2',3,4,4',5-Hexachlorobiphenyl #138 (35065-28-2) 2,2',3,4',5,5',6-Heptachlorobiphenyl #187 (52663-68-0) 2,2',3,3',4,4'-Hexachlorobiphenyl #128 (38380-07-3) 2,2',3,4,4',5,5'-Heptachlorobiphenyl #180 (35065-29-3) 2,2',3,3',4,4',5-Heptachlorobiphenyl #170 (35065-30-6) 2,2',3,3',4,4',5,5-Octachlorobiphenyl #195 (52663-78-2) 2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl #206 (40186-7-2-9) Decachlorobiphenyl #209 (2051-24-3) 3,3',4,4'-Tetrachlorobiphenyl #77[c] (32598-13-3) 3,3',4,4',5-Pentachlorobiphenyl #126[c] (??) 3,3',4,4',5,5'-Hexachlorobiphenyl #169[c] (32774-16-6)	1	Soxhlet extraction into hexane/methylene chloride; analysis by gas chromatography/ electron capture detection (GC/ECD) recommended	EPA 682 (NOAA, 1988); 8080A (EPA, 1990)

9.0 Water Chemistry

The primary purposes of the water samples and the field chemical measurements are to determine:

- Acid-base status
- Trophic condition (nutrient enrichment)
- Chemical Stressors
- Classification of water chemistry type

A 4-L bulk sample was collected at the X-site for measurement of the major cations and anions, nutrients, total iron and manganese, turbidity and color. Syringe samples also were collected from the same location for analysis of pH, dissolved inorganic carbon, and monomeric aluminum species. In situ and streamside measurements were made using field meters for specific conductance (or conductivity), dissolved oxygen (DO), and temperature. DO and temperature were only collected at sites where sediment oxygen demand was measured and these usually were those included in the physical habitat assessment.

Table 9-1 describes methods for field measurements and Table 9-2 indicates analytical methods for laboratory measurements.

Table 9-1. Field measurement methods for water chemistry.

Variable or Measurement	Summary of Method	References
Temperature, in situ	Measured at mid-channel using thermistor probe.	EPA 150.6; Chaloud et al. (1989)
Dissolved oxygen, in situ	Measured at mid-channel (streams) using membrane electrode and meter.	EPA 360.1; Chaloud et al. (1989)
Conductivity, field	Conductivity meter; reading corrected to 25 C	EPA 360.1

Table 9-2. Laboratory analytical methods for water chemistry.

Analyte	Summary of Method	References
pH, closed system	Sample collected and analyzed without exposure to atmosphere; electrometric determination (pH meter and glass combination electrode)	EPA 150.6 (modified); U.S. EPA (1987)
pH, equilibrated	Equilibration with 300 ppm CO2 for 1 hr prior to analysis; Electrometric determination (pH meter and glass combination electrode)	EPA 150.6 (modified); U.S. EPA (1987)
Acid Neutralizing Capacity (ANC)	Acidimetric titration to pH 3.5, with modified Gran plot analysis	EPA 310.1 (modified); U.S. EPA (1987)
Carbon, dissolved[a] inorganic (DIC), closed system	Sample collected and analyzed without exposure to atmosphere; acid-promoted oxidation to CO2, with detection by infrared spectrophotometry	U.S. EPA (1987)
Carbon, dissolved organic (DOC)	UV-promoted persulfate oxidation, detection by infrared spectrophotometry	EPA 415.2, U.S. EPA (1987)
Conductivity	Electrolytic (conductance cell and meter)	EPA 120.6, U.S. EPA (1987)
Aluminum, total dissolved	Atomic absorption spectroscopy (graphite furnace)	EPA 202.2, U.S. EPA (1987)
Aluminum, monomeric and organic monomeric	Collection and analysis without exposure to atmosphere. Portion of sample passed through a cation exchange column before analysis to obtain estimate of organic-bound fraction. Colorimetric analysis (automated pyrocatechol violet).	APHA 3000-A1 E.; APHA (1989), U.S. EPA (1987)
Major Cations (dissolved)		
Calcium, Magnesium, Sodium, Potassium	Atomic absorption spectroscopy (flame)	EPA 200.6, U.S. EPA (1987)
Ammonium	Colorimetric (automated phenate)	EPA 350.7; U.S. EPA (1987)
Major Anions (dissolved)		
Chloride, Nitrate, Sulfate	Ion chromatography	EPA 300.6; U.S. EPA (1987)
Silica, dissolved	Automated colorimetric (molybdate blue)	EPA 370.1 (modified) U.S. EPA (1987)
Phosphorus, total	Acid-persulfate digestion with automated colorimetric determination (molybdate blue)	USGS 1-4600-78; Skougstad et al. (1979), U.S. EPA (1987)
Nitrogen, total	Alkaline persulfate digestion with determination of nitrate by cadmium reduction and determination of nitrite by automated colorimetry (EDTA/sulfanilimide).	EPA 353.2 (modified); U.S. EPA (1987)
True Color	Visual comparison to calibrated glass color disks	EPA 100.2 (modified), APHA 204 A.; U.S. EPA (1987)
Turbidity	Nephelometric	APHA 214 A., EPA 180.1; U.S. EPA (1987)
Total Suspended Solids (TSS)	Gravimetric	EPA 160.3; APHA (1989)

[a] *For DIC, "dissolved" is defined as that portion passing through a 0.45 m nominal pore size filter. For other analytes, "dissolved" is defined as that portion passing through a 0.4 m pore size filter (Nucleopore or equivalent).*

10.0 Stressor Identification

Stressors were identified based on the 305(b) EPA Region and state Report to Congress, input from EPA and state personnel, and knowledge of emerging issues in the Mid-Atlantic region. The focus was on stressors that effected stream ecosystems. There was an emphasis on including not only chemical, but also physical and biological stressors. Habitat indicators and metrics were selected so that potential stressors to both riparian and instream habitat might be determined. Non-native fish were included as potential stressors in the development of earlier work on fish IBI indices (Karr 1981, 1991; Karr et. al. 1986; McCormick et al. 2001). The definition of biotic integrity, as used by Karr (1991) indicates that non-native fish detract from the biotic integrity of stream ecosystems. There has been considerable research on competitive and predatory interactions of non-native game fish on native fish species (see Nico et al. 1999), which indicates non-native fish can be stressors on native fish species. Considering non-native fish a potential stressor on stream ecosystems, therefore, was not unreasonable and can be scientifically justified. The issue of non-native game fish species as potential stressors revolves around sociopolitical designations of uses in stream ecosystems and the subsequent management to achieve these designated uses. Presenting information on the proportion of stream miles with non-native species permits an informed discussion on whether these species are considered stressors or success stories (see the Highlands Streams Report).

The Highlands Streams Report refers to potential stressors because the linkage between stressors and effects in Highland stream ecosystems has not been determined. Statistical association and regression analyses are in progress, including exploratory analyses using multivariate statistical procedures such as cluster, principal component, and factor analysis. Within stream association analyses are being conducted to evaluate the relationships among habitat (e.g., instream and riparian indicators, metrics, and indices), chemical (e.g., nutrient concentrations, SOD), and biological indicators and metrics with fish and benthic assemblages. Similar analyses are being conducted to evaluate the relationships among land use/land cover indicators and instream indicators. These analyses were not included in the Highlands Stream Report and, therefore, are not included in this Technical Support Document. Subsequent reports will provide results and supporting documentation for these analyses.

11.0 Classification for Reporting Results

11.1 General Classification Approach

To compute population estimates with reasonable confidence intervals generally requires about 50 samples per reporting unit (see Section 2.1 EMAP Design). The confidence limits for a sample size of 30 and 50 (proportion of the streams in poor condition < 25%), are about ± 18 and 12%, respectively. Reporting units with sample sizes less than 30 are not recommended. The sample size for many of the desired reporting units in the Highlands (e.g., Level III or Level IV ecoregions, 8-digit HUC watersheds, states) ranged from 6 samples to 83 samples per reporting unit. There were differential numbers of samples collected by media, which further limited the number of samples available for each reporting unit. For example, there were 448 sites sampled for stream chemistry and 446 for benthos across the Mid-Atlantic in 1993-94; 289 sites were sampled for fish, and 159 sites sampled for physical habitat (Table 2-1). The decision made for the Highlands Streams Report was to use the lowest common denominator in determining the aggregation needed to have about 30-50 sites per reporting unit for any of the media indicators. It would have been confusing to the reader if some media were omitted because of insufficient sample sizes for reasonable estimates in that reporting unit. This would have eliminated comparisons across reporting units for all media. The decision was made to include all the media and aggregate smaller reporting units until the sample size was appropriate for making reasonable population estimates. Therefore, both Level III and IV ecoregions and 8-digit HUC watersheds were aggregated to achieve the desired sample size. The results reported in the Highlands Streams Report, by indicator type and aggregated reporting unit, are shown in Table 11-1 a, b, and c.

The number of samples by media by Level III and IV ecoregions and 8-digit HUC watershed reporting units are listed in Table 11-2. It is possible to make population estimates for some indicators in selected media with these non-aggregated reporting units and still have reasonable confidence limits.

11.2 Watershed Classification

Watershed aggregations were based on the larger drainage basins into which the aggregated watersheds contributed. The Susquehanna had a sufficient number of samples for all media so aggregation was unnecessary. The Allegheny and Monongahela watersheds were aggregated because these two rivers join in Pittsburgh to form the Ohio River. The Kanawha and Upper Ohio watersheds were aggregated because these both drain into the Ohio River.

11.3 Ecoregion Classification

Ecoregion aggregations were based on conversations with J. Omernik, author of the Level III and Level IV ecoregions for the U.S. (Omernik 1987, 1995). As indicated in Section 1, ecoregions were aggregated to ensure there were adequate sample sizes in each aggregated ecoregion to make population estimates with reasonable confidence limits.

Table 11- 1a. Percent of stream miles in good condition or affected by potential stressors for the Mid-Atlantic Highlands, four Highland ecoregions, three watersheds, and two states.

	ECOREGION					WATERSHED			STATE	
Constituents	Mid-Atlantic Region	North-Central Appalachians	Ridge & Blue Ridge	Valley	Western Appalachians	Chesapeake	Allegheny-Monongahela	Kanawha-Upper Ohio	Pennsylvania	West Virginia
Fish IBI[1]	17	15	28	23	4	25	11	12	14	13
EPT Index[1]	25	33	46	16	3	32	27	14	25	20
Non-native Fish[2]	48	52	61	52	37	59	42	57	46	58
Fish Tissue Contamination[3]										
Carcinogens	46	66	36	37	41	47	59	48	53	56
Mercury	52	70	41	53	41	48	64	57	59	57
Mine Drainage[4]	86	76	100	100	76	97	81	79	84	87
Acidic Deposition[4]	89	76	92	98	100	89	74	94	86	86
Total Nitrogen[6]	85	93	98	70	68	85	91	83	73	88
Total Phosphorus[5]	90	97	95	89	74	95	89	83	84	93
Riparian Habitat	48	40	92	19	35	52	58	39	46	41
Instream Habitat	35	50	47	27	21	31	48	29	33	43
Watershed Condition[1]	45	52	77	18	2	45	47	48	35	64

[1] *% stream miles in good condition*
[2] *% stream miles without non-native fish*
[3] *% stream miles without at least one constituent above human health carcinogen criteria or above mammalian mercury criteria*
[4] *% stream miles not affected*
[5] *% stream miles with TP <50 µg/ L EPA guideline*
[6] *% stream miles with TN <1, 300 µg/ L based on EPA TP guideline*

Table 11- 1b. Percent of stream miles in fair condition or affected by potential stressors for the Mid-Atlantic Highlands, four Highland ecoregions, three watersheds, and two states.

	ECOREGION					WATERSHED			STATE	
Constituents	Mid-Atlantic Region	North-Central Appalachians	Ridge & Blue Ridge	Valley	Western Appalachians	Chesapeake	Allegheny-Monongahela	Kanawha-Upper Ohio	Pennsylvania	West Virginia
Fish IBI[1]	36	32	44	37	32	39	51	26	46	20
EPT Index[1]	48	43	41	48	61	48	52	50	48	55
Non-native Fish										
Fish Tissue Contamination										
Carcinogens										
Mercury										
Mine Drainage										
Acidic Deposition										
Total Nitrogen[2]	10	5	<1	15	24	8	7	17	19	2
Total Phosphorus[3]	5	2	4	8	6	4	9	4	8	2
Riparian Habitat[1]	28	28	3	48	37	36	14	31	34	33
Instream Habitat[1]	40	40	26	45	51	44	46	41	48	39
Watershed Condition[1]	28	21	13	48	4	35	17	30	27	28

[1] *% stream miles in fair condition*

[2] *% stream miles with TN >1, 300 µg/ L but <3, 000 µg/ L based on TP guideline*

[3] *% stream miles with 100 > TP > 50 µg/ L EPA guideline*

Table 11- 1c. Percent of stream miles in poor condition or affected by potential stressors for the Mid-Atlantic Highlands, four Highland ecoregions, three watersheds, and two states.

	ECOREGION					WATERSHED			STATE	
Constituents	Mid-Atlantic Region	North-Central Appalachians	Ridge & Blue Ridge	Valley	Western Appalachians	Chesapeake	Allegheny-Monongahela	Kanawha-Upper Ohio	Pennsylvania	West Virginia
Fish IBI[1]	31	43	14	31	30	23	31	41	27	44
EPT Index[1]	27	24	14	46	37	20	22	36	27	25
Non-native Fish[2]	31	36	19	40	19	31	46	20	44	26
Fish Tissue Contamination[3]										
Carcinogens	10	12	5	16	7	5	19	9	15	1
Mercury	4	8	0	0	6	4	14	0	9	0
Mine Drainage[4]	14	24	0	0	24	3	20	21	16	13
Acidic Deposition[4]	11	24	8	2	0	11	26	7	14	14
Total Nitrogen[6]	4	2	1	15	24	7	2	17	8	1
Total Phosphorus[5]	5	1	1	3	20	2	2	13	9	5
Riparian Habitat	24	31	5	34	28	12	28	30	21	26
Instream Habitat	25	10	28	28	38	25	6	30	19	18
Watershed Condition[1]	25	27	10	35	31	21	36	22	38	9

[1] % stream miles in poor condition
[2] % stream miles with non-native fish
[3] % stream miles with at least one constituent above human health carcinogen criteria or above mammalian mercury criteria
[4] % stream miles affected
[5] % stream miles with TP >100 µg/ L EPA guideline
[6] % stream miles with TN >3, 000 µg/ L based on EPA TP guideline

Table 11- 2. Number of stream samples for each medium in the Mid-Atlantic Highlands, four Highland ecoregions, three watersheds, and two states.

	ECOREGION					WATERSHED			STATE	
Constituents	**Mid-Atlantic Region**	**North-Central Appalachians**	**Ridge & Blue Ridge**	**Valley**	**Western Appalachians**	**Chesapeake**	**Allegheny-Monongahela**	**Kanawha-Upper Ohio**	**Pennsylvania**	**West Virginia**
Fish IBI	210	31	53	104	22	111	27	40	81	41
EPT Index	391	156	89	113	33	185	73	84	172	91
Non-native Fish	110	36	23	23	28	33	25	41	74	37
Fish Tissue Contamination										
Carcinogens	104	40	19	26	19	35	25	34	61	24
Mercury	104	40	19	26	19	35	25	34	61	24
Mine Drainage	357	148	82	104	23	174	64	69	157	90
Acidic Deposition	357	148	82	104	23	174	64	69	157	90
Total Nitrogen	357	148	82	104	23	174	64	69	157	90
Total Phosphorus	357	148	82	104	23	174	64	69	157	90
Riparian Habitat	107	34	22	23	28	33	24	40	75	35
Instream Habitat	107	34	22	23	28	33	24	40	75	35
Watershed Condition	391	156	89	113	33	185	73	84	207	105

12.0 Information Management

A description of information management practices for EMAP are found in U.S. EPA (1999). The collection of streams monitoring data in the EMAP and MAIA programs by EPA and non-EPA participants is coordinated by the EPA Western Ecology Division (WED – Corvallis, Oregon) under the direction of the Surface Waters Principal Investigator, John Stoddard. Raw data are transferred to WED and then are forwarded to researchers acting as indicator leads. These individuals are responsible for coordination of indicator development and assessment of ecological condition in the Mid-Atlantic region. The indicator leads for the data presented in the MAHA Streams Report are as follows:

- **Macroinvertebrates:**
  Donald Klemm
  EPA National Exposure Research Laboratory, Cincinnati
- **Fish:**
  Frank McCormick
  EPA National Exposure Research Laboratory, Cincinnati
- **Physical Habitat:**
  Philip Kaufmann
  EPA National Health and Environmental Effects Laboratory, Corvallis
- **Watershed Risk:**
  Robert Hughes
  EPA National Health and Environmental Effects Laboratory, Corvallis

Upon completion of indicator research, raw and summarized data are maintained by WED Information Management Team (POC: Marlys Cappaert) in SAS and Arc/Info on a Unix server.

Metadata for all data sets are produced in EMAP data catalog format and are provided along with station-specific data on the EMAP public web site:

http://www.epa.gov/emap/html/dataI/surfwatr/data/mastreams/

Metadata and data sets currently residing on this site are:

- Benthic macroinvertebrate counts and metrics
- Fish assemblage counts, metrics, and identification codes
- Fish tissue contaminants for metals and organics
- Watershed characteristics
- Physical habitat metrics
- Sample site information
  and
- Stream chemistry measurements

These data are downloadable in the form of comma-delimited text (.txt) files. WED personnel may be contacted for access to these and other MAHA data products in electronic or printed form.

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Appendix Table A-1. Assessment questions for the Mid-Atlantic Highland streams.

Mid-Atlantic Highland Assessment (MAHA) Preliminary Set of Questions	
Resource (Population) Characterization	
Category - Physical Attributes	
1.	How many stream miles are estimated to be in MAHA? Ecoregions?
2.	How many stream miles of wadable streams are estimated to be in MAHA? Ecoregions? States? Where?
3.	How many stream miles of each stream order are estimated to be in MAHA? Ecoregions? States?
4.	How many stream miles in MAHA? Ecoregions? States? Are estimated to be remote?
5.	What % of streams in MAHA, Ecoregions, states, had water in them (i.e., were not dry) at the time of sampling?
6.	What % of streams in MAHA, Ecoregions, states, have gravel bottoms? Mud bottoms?
7.	What % of stream miles in MAHA, Ecoregions, states are estimated to be in 1. Public ownership 2. Private ownership
8.	What % of stream miles in MAHA, Ecoregions, states have buffer strips (i.e., trees, shrubs, vegetation - not cultivated, pasture or asphalt)?
9.	What % of stream miles in MAHA, Ecoregions, states have in-stream obstructions?
10.	What % of stream miles have bank revetment or artificial banks?
Category - Chemical Attributes	
11.	What are the distributions of stream ANC, pH, SO_4, AL, conductivity values in MAHA, Ecoregions, states?
12.	What are the distributions of stream TP, NO_3, and TSS concentrations in MAHA, Ecoregions, states?
13.	What is the distribution of stream DO, % saturation values in MAHA, Ecoregions, states?
14.	What is the distribution of stream SOD in MAHA, Ecoregions, states?

Appendix Table A-1 (con't). Assessment questions for the Mid-Atlantic Highland streams.

Mid-Atlantic Highland Assessment (MAHA) Preliminary Set of Questions	
Category - Biological Attributes: Fish	
15.	Which fish species (and assemblages) are most ubiquitous in MAHA, Ecoregions, states?
16.	What is the spatial distribution of the species listed above?
17.	What % of stream miles in MAHA, Ecoregions, states, have exotic fish species?
18.	What is average number of fish species/site for: 1. Ecoregion 2. State 3. MAHA
19.	What is cumulative fish species richness for Ecoregion, MAHA, states?
20.	What % of stream miles in MAHA, Ecoregions, states had fish with observed abnormalities?
21.	What % of stream miles in MAHA Ecoregions states have threatened and endangered species?
Category - Biological Attributes: Fishability	
22.	What % of stream miles in MAHA Ecoregions states have game fish?
23.	What % of stream miles in MAHA, Ecoregions, states have legal size game fish?
24.	What % of stream miles in MAHA Ecoregions states are cold vs warm water streams as determined by the fish species?
25.	What % of stream miles in MAHA, Ecoregions, states have size-distributions indicative of natural reproducing game fish populations? 1. Specific fish assemblages of interest 2. Cold water 3. Cool water (i.e., small mouth bass) 4. Warm water
26.	What % of stream miles have fish tissue contaminant residue levels exceeding human health or wildlife criteria?
Category - Biological Attributes: Benthos	
27.	What is the distribution of the total number of Benthic species/site in streams in MAHA, Ecoregions, states?
28.	What is the distribution of stream E-P-T scores for MAHA, Ecoregions, states?

Appendix Table A-1 (con't). Assessment questions for the Mid-Atlantic Highland streams.

Mid-Atlantic Highland Assessment (MAHA) Preliminary Set of Questions
Category - Landscape Characteristics
29. What % of the area in MAHA Ecoregions states are in the following land use categories: 1. Agriculture 2. Forest 3. Urban 4. Wetlands (includes lakes, streams)
30. What is the distribution of the area of the above land use categories in watersheds, by stream order?
31. What % of stream miles have Superfund sites in the watershed?
32. What % of stream miles have point sources in the watershed?
33. What % of watersheds have gypsy moth infestations in the watershed that have been sprayed?
34. What % of watersheds have had pesticide or nutrient applications in the watershed?
35. What % of stream miles receive storm water discharge?
36. Where are the minimally impacted streams (reference conditions) and what are their landuse/landscape characteristics?
37. What % of stream miles are associated with heavily disturbed watersheds?
38. What is the distribution of connectivity (shape - complexity, dominance) indices for watersheds in MAHA, Ecoregions, states?
39. What are the changes for each questions above from 1970–1990?
Assessment Questions
Category - Biotic Integrity
40. What % of steam miles in MAHA, Ecoregions states have fish IBI scores indicating good, fair, and poor stream conditions? 1. Species Richness 2. % Intolerants 3. Cumulative Index, IBI (Ecoregion, WS) *[Note: Want similar scale across the region - vary metrics and scores, but use the same process]*

Appendix Table A-1 (con't). Assessment questions for the Mid-Atlantic Highland streams.

Mid-Atlantic Highland Assessment (MAHA) Preliminary Set of Questions	
41.	What % of stream miles in MAHA, Ecoregions states in study area have EPT scores that indicate good, fair, and poor stream conditions? 1. E-P-T 2. Sampling richness - % dominance 3. Summary index, e.g., HBI
42.	What % of stream miles in MAHA, Ecoregions states have periphyton assemblages that indicate nutrient enrichment? 1. Sampling richness 2. Biomass (i.e., - chl/cm^2) 3. % Abundance or filamentous forms *[Note: May be an index period question - calibrate?]*
Category - Habitat Integrity	
43.	What % of steam miles in MAHA, Ecoregion, states have riparian habitat scored in good, fair, or poor condition?
44.	What % of stream miles in MAHA, Ecoregion, states have aesthetically-pleasing habitat?
Category - Stream Acidity	
45.	What % of chronically acidic stream miles in MAHA, Ecoregions, states are associated with AMD or acidic deposition as measured by: ANC, pH, SO_4, conductivity.
46.	What % of stream miles in MAHA, Ecoregions, states are susceptible to acidic deposition?
Category - Biological Resource - Stressor	
47.	What % of stream miles in (MAHA) Ecoregions states with degraded biotic integrity are associated with: 1. AMD 2. Acidic deposition 3. Eutrophication 4. Habitat degradation 5. Exotic
48.	What % of stream miles with degraded biotic integrity are associated with specific chemical stressors such as metals (Zn, Cr, Cd), organics (TCDD, PCB's, etc.)?
49.	What is the association of biotic integrity with different geologic types?

Appendix Table A-1 (con't). Assessment questions for the Mid-Atlantic Highland streams.

Mid-Atlantic Highland Assessment (MAHA) Preliminary Set of Questions	
50.	What is the association between biotic integrity and elevation?
51.	What % of stream miles in MAHA, Ecoregions, states would be expected to have brook trout (mussels, endangered species, etc.) if: 1. Acidity 2. Eutrophication 3. Toxics 4. Habitat degradation were not impacting the stream system?
52.	What are potential recovery times for degraded systems following improvement?
53.	What % of stream miles in MAHA, Ecoregions, states with degraded biotic integrity are associated with: 1. % Agric - Till/No-Till 2. % Forest - Forest mgt. Practices (clear-cutting/selective) 3. Width of buffer strips 4. Erosion potential 5. Number of animal (i.e., poultry) production units 6. % urban 7. Interaction among stressor - land use - biotic responses
54.	What % of stream miles in MAHA Ecoregions, states with degraded biotic integrity are associated with landscape indices such as: 1. Connectivity 2. Shape - complexity 3. Dominance
55.	What changes have occurred in the % stream miles in MAHA, Ecoregions, states with degraded biotic integrity that are associated with changes in landscape indices? 1970–1980–1990
56.	What % of stream miles in MAHA, Ecoregions, states have degraded biotic integrity that is associated with indicators of condition from other EMAP/REMAP Resources (e.g., Forest canopy index, Agricultural Lands erosion potential indices)?
57.	What % of stream miles in MAHA, Ecoregions, states have biotic integrity values that indicate cumulative impacts from different land uses in the watershed?

Appendix Table 2. Station locations, ecoregion designation, and parameters measured.

STRM_ID	SITECLS	STUDY	YEAR	STRMNAME	ECOAREA	ECOREG	COUNTY	LAT_DD	LON_DD	ORD	FLOWSITE	BENTH RBPHAB	FISH	FISH TISS	STRM CHEM	PHAB DO/TEMP
MDR01S	REF	REF	1993	MARSH RUN		67a	WASHINGTON	39.57722	77.75472		FLOWING	Y	Y	N	Y	Y
MDR02S	REF	REF	1993	COLLIER RUN		67c	ALLEGANY	39.58158	78.71860		FLOWING	Y	Y	N	Y	Y
MDR03S	REF	REF	1993	MIDDLE FORK		67d	GARRETT	39.51417	79.16167		FLOWING	Y	Y	N	Y	Y
MDR04S	REF	REF	1994	ST. JAMES RUN	VALLEY	67a	WASHINGTON	39.57167	77.75444	3	FLOWING	Y	Y	N	Y	Y
MDR05S	REF	REF	1994	COLLIER RUN	RIDGE	67c	ALLEGANY	39.58194	78.71861	2	FLOWING	Y	Y	N	Y	Y
PAR01S	REF	REF	1993	FALLING SPRING		67a	FRANKLIN	39.91111	77.61667		FLOWING	Y	Y	N	Y	Y
PAR02S	REF	REF	1993	PENNS CR.		67a	CENTRE	40.86472	77.60833		FLOWING	Y	Y	N	Y	Y
PAR03S	REF	REF	1993	WOODEN BRIDGE CR.		67b	FULTON	40.05639	78.04778		FLOWING	Y	Y	N	Y	Y
PAR04S	REF	REF	1993	SPRUCE RUN		67b	COLUMBIA	41.13333	76.57417		FLOWING	Y	Y	N	Y	Y
PAR05S	REF	REF	1993	SLATEFORD CR.		67b	NORTHAMPTON	40.94583	75.12667		FLOWING	Y	Y	N	Y	Y
PAR06S	REF	REF	1993	TUSCARORA CR.		67b	JUNIATA	40.27016	77.73835		FLOWING	Y	Y	N	Y	Y
PAR07S	REF	REF	1993	WHITE DEER CR.		67c	UNION	41.05611	77.07583		FLOWING	Y	Y	N	Y	Y
PAR08S	REF	REF	1993	BOBS CR.		67c	BEDFORD	40.27082	78.59822		FLOWING	Y	Y	N	Y	Y
PAR09S	REF	REF	1993	WILD CR.		67c	CARBON	40.93639	75.59778		FLOWING	Y	Y	N	Y	Y
PAR10S	REF	REF	1993	MILL CR.		67d	LYCOMING	41.29583	76.85250		FLOWING	Y	Y	N	Y	Y
PAR11S	REF	REF	1993	LITTLE WILLS CR.		67d	BEDFORD	39.93111	78.67361		FLOWING	Y	Y	N	Y	Y
PAR13S	REF	REF	1994	FALLING SPRING	VALLEY	67a	FRANKLIN	39.91917	77.62694	1	FLOWING	Y	Y	N	Y	Y
PAR14S	REF	REF	1994	PENNS CR	VALLEY	67a	CENTRE	40.85889	77.58139	2	FLOWING	Y	Y	N	Y	Y
PAR15S	REF	REF	1994	WOODEN BRIDGE CR	VALLEY	67b	FULTON	40.07139	78.03333	1	FLOWING	Y	Y	N	Y	Y
PAR16S	REF	REF	1994	SPRUCE RUN	VALLEY	67b	COLUMBIA	41.10833	76.55694	2	FLOWING	Y	Y	N	Y	Y
PAR17S	REF	REF	1994	SLATEFORD CR	VALLEY	67b	NORTHHAMPTON	40.94528	75.12139	1	FLOWING	Y	Y	N	Y	Y
PAR18S	REF	REF	1994	TUSCARORA CR	VALLEY	67b	HUNTINGDON	40.22278	77.77583	2	FLOWING	Y	Y	N	Y	Y
PAR19S	REF	REF	1994	WHITE DEER CR	RIDGE	67c	UNION	41.03889	77.08639	2	FLOWING	Y	Y	N	Y	Y
PAR20S	REF	REF	1994	BOBS CR	RIDGE	67c	BEDFORD	40.27611	78.60389	2	FLOWING	Y	Y	N	Y	Y
PAR21S	REF	REF	1994	WILD CR	RIDGE	67c	CARBON	40.93583	75.59861	2	FLOWING	Y	Y	N	Y	Y
PAR22S	REF	REF	1994	MILL CR	RIDGE	67d	LYCOMING	41.29556	76.85333	3	FLOWING	Y	Y	N	Y	Y
PAR23S	REF	REF	1994	WOLF CAMP RUN	RIDGE	67d	BEDFORD	39.91611	78.69639	2	FLOWING	Y	Y	N	Y	Y
VAR01S	REF	REF	1993	WALKER CR.		67a	BLAND	37.05972	81.13861		FLOWING	Y	Y	N	Y	Y
VAR02S	REF	REF	1993	SINKING CR.		67a	CRAIG	37.39528	80.31222		FLOWING	Y	Y	N	Y	Y
VAR03S	REF	REF	1993	S. BR. POTOMAC R.		67a	HIGHLAND	38.48694	79.57222		FLOWING	Y	Y	N	Y	Y
VAR04S	REF	REF	1993	MOSSY CR.		67a	AUGUSTA	38.35750	79.03139		FLOWING	Y	Y	N	Y	Y
VAR05S	REF	REF	1993	LITTLE WOLF RUN		67b	WASHINGTON	36.68889	82.28056		FLOWING	Y	Y	N	Y	Y
VAR06S	REF	REF	1993	ELLIOTT CR.		67b	MONTGOMERY	37.11667	80.27861		FLOWING	Y	Y	N	Y	Y
VAR07S	REF	REF	1993	BIG CR.		67b	BOTETOURT	37.73667	79.78889		FLOWING	Y	Y	N	Y	Y
VAR08S	REF	REF	1993	LICK CR.		67c	SMYTH	36.97861	81.45583		FLOWING	Y	Y	N	Y	Y
VAR09S	REF	REF	1993	STONY CR.		67c	GILES	37.41389	80.58417		FLOWING	Y	Y	N	Y	Y
VAR10S	REF	REF	1993	BULLPASTURE R.		67c	HIGHLAND	38.36111	79.47694		FLOWING	Y	Y	N	Y	Y
VAR11S	REF	REF	1993	BEAR CR.		67d	SMYTH	36.89444	81.43944		FLOWING	Y	Y	N	Y	Y
VAR12S	REF	REF	1993	MOSS RUN		67d	ALLEGHANY	37.78694	80.11389		FLOWING	Y	Y	N	Y	Y
VAR13S	REF	REF	1993	NORTH R.		67d	AUGUSTA	38.33472	79.23944		FLOWING	Y	Y	N	Y	Y
VAR14S	REF	REF	1994	WALKER CR	VALLEY	67a	BLAND	37.05472	81.17194	2	FLOWING	Y	Y	N	Y	Y
VAR15S	REF	REF	1994	SINKING CR	VALLEY	67a	CRAIG	37.35194	80.38389	2	FLOWING	Y	Y	N	Y	Y
VAR16S	REF	REF	1994	MOSSY CR	VALLEY	67a	AUGUSTA	38.35917	79.03000	2	FLOWING	Y	Y	N	Y	Y
VAR17S	REF	REF	1994	ELLIOT CR	VALLEY	67b	MONTGOMERY	37.11056	80.30194	2	FLOWING	Y	Y	N	Y	Y
VAR18S	REF	REF	1994	SINKING CR	VALLEY	67b	BOTETOURT	37.74250	79.73833	1	FLOWING	Y	Y	N	Y	Y
VAR19S	REF	REF	1994	LICK CR	RIDGE	67c	SMYTH	36.98750	81.43722	2	FLOWING	Y	Y	N	Y	Y
VAR20S	REF	REF	1994	STONY CR	RIDGE	67c	GILES	37.41611	80.57972	3	FLOWING	Y	Y	N	Y	Y
VAR21S	REF	REF	1994	BEAR CR	RIDGE	67d	SMYTH	36.91278	81.39917	2	FLOWING	Y	Y	N	Y	Y
VAR22S	REF	REF	1994	MOSS RUN	RIDGE	67d	ALLEGHANY	37.78750	80.12861	2	FLOWING	Y	Y	N	Y	Y
VAR23S	REF	REF	1994	NORTH R	RIDGE	67d	AUGUSTA	38.35028	79.25694	3	FLOWING	Y	Y	N	Y	Y
VAR25S	REF	REF	1994	BROAD CR	VALLEY	67a	ROCKBRIDGE	37.71417	79.50694	2	FLOWING	Y	Y	N	Y	Y
WVR01S	REF	REF	1993	TUSCARORA CR.		67a	BERKLEY	39.46667	78.02500		FLOWING	Y	Y	N	Y	Y
WVR02S	REF	REF	1993	MIDDLE FK. SLEEPY CR.		67b	MORGAN	39.47222	78.24778		FLOWING	Y	Y	N	Y	Y
WVR03S	REF	REF	1993	DILLONS RUN		67c	HAMPSHIRE	39.28444	78.45111		FLOWING	Y	Y	N	Y	Y

Appendix Table 2. Station locations, ecoregion designation, and parameters measured.

STRM_ID	SITECLS	STUDY	YEAR	STRMNAME	ECOAREA	ECOREG	COUNTY	LAT_DD	LON_DD	ORD	FLOWSITE	BENTH RBPHAB	FISH	FISH TISS	STRM CHEM	PHAB DO/TEMP
WVR04S	REF	REF	1993	LITTLE R.	RIDGE	67d	POCAHONTAS	38.62222	79.78611		FLOWING	Y	Y	N	Y	Y
WVR05S	REF	REF	1994	TUSCARORA CR	VALLEY	67a	BERKLEY	39.46667	78.03667	2	FLOWING	Y	Y	N	Y	Y
WVR06S	REF	REF	1994	MIDDLE FORK SLEEPY CR	VALLEY	67b	MORGAN	39.49917	78.22972	2	FLOWING	Y	Y	N	Y	Y
WVR07S	REF	REF	1994	DILLONS RUN	RIDGE	67c	HAMPSHIRE	39.27000	78.46861	1	FLOWING	Y	Y	N	Y	Y
DE750S	TARGET	EMAP	1994	TUSOCKY BR	PIED/CP	PIED/CP	SUSSEX	38.52530	75.63110	2	FLOWING	Y	Y	Y	Y	Y
MD507S	TARGET	EMAP	1993	S. BR. LAUREL RUN		NSS-APP	GARRETT	39.68369	79.47240	1	FLOWING	Y	Y	N	Y	Y
MD508S	TARGET	TIME	1993	WATERS RUN		67d	GARRETT	39.54469	79.18200	1	FLOWING	Y	Y	N	Y	N
MD510S	TARGET	TIME	1993	BLACKLICK RUN		67d	GARRETT	39.60595	79.08000	2	FLOWING	Y	Y	N	Y	N
MD511S	TARGET	TIME	1993	TERRAPIN RUN		67d	ALLEGANY	39.65929	78.42956	1	FLOWING	Y	Y	N	Y	N
MD512S	TARGET	TIME	1993	NONAME TRIB TOWN CR (GERLOCK HOLLOW)		67d	ALLEGANY	39.61331	78.56847	1	FLOWING	Y	Y	N	Y	N
MD513S	TARGET	REMAP	1993	MEADOW BROOK		67a	WASHINGTON	39.67982	77.89979	1	FLOWING	Y	Y	N	Y	N
MD750S	TARGET	EMAP	1994	NNT NORWICH CR	PIED/CP	PIED/CP	TALBOT	38.92420	75.98710	1	FLOWING	Y	Y	Y	Y	Y
MD751S	TARGET	EMAP	1994	MIDDLE PALUXENT R	PIED/CP	PIED/CP	HOWARD	39.29130	76.97090	3	FLOWING	Y	Y	Y	Y	Y
MD752S	TARGET	EMAP	1994	NNT NORTH BR R	RIDGE	67d	ALLEGANY	39.59960	78.66680	1	INTERUPT	Y	Y	N	Y	Y
MD754S	TARGET	EMAP	1994	NNT GILBERT SWAMP RUN	PIED/CP	PIED/CP	CHARLES	38.47150	76.85190	1	FLOWING	Y	Y	Y	Y	Y
MD755S	TARGET	TIME	1994	SAVAGE R	RIDGE	67d	GARRETT	39.59777	79.05660	3	FLOWING	Y	Y	N	Y	N
MD756S	TARGET	REMAP	1994	BEAVER CR	VALLEY	67a	WASHINGTON	39.61050	77.61600	2	FLOWING	Y	Y	N	Y	N
MD757S	TARGET	TIME+	1994	NNT NORTH BR POTOMAC R	RIDGE	67c	ALLEGANY	39.57560	78.84810	2	FLOWING	Y	N	N	Y	N
NY500S	TARGET	EMAP	1993	RED BROOK		NSS-APP	SULLIVAN	41.81901	74.53834	1	FLOWING	Y	N	N	Y	N
NY502S	TARGET	TIME	1993	WEST BRANCH DELAWARE		NSS-APP	DELAWARE	42.35104	74.69288	2	FLOWING	Y	N	N	Y	N
NY503S	TARGET	TIME	1993	BLACK BROOK		NSS-APP	ULSTER	42.03058	74.59311	1	FLOWING	Y	N	N	Y	N
NY752S	TARGET	TIME	1994	STONY CLOVE CR	NORTHAPPS	CATSKILL	GREENE	42.12949	74.25890	1	FLOWING	Y	N	N	Y	N
NY753S	TARGET	TIME	1994	WEST BR DELAWARE R	NORTHAPPS	CATSKILL	DELAWARE	42.35566	74.68950	2	FLOWING	Y	N	N	Y	N
NY754S	TARGET	TIME	1994	W BROOK	NORTHAPPS	CATSKILL	DELAWARE	42.21244	75.11900	3	FLOWING	Y	N	N	Y	N
NY755S	TARGET	TIME	1994	NNT PLATTE KILL	NORTHAPPS	CATSKILL	DELAWARE	42.16819	74.69100	1	FLOWING	Y	N	N	Y	N
PA505S	TARGET	EMAP	1993	PLUM CR.		67b	BERKS	40.44536	76.05247	1	FLOWING	Y	Y	Y	Y	Y
PA508S	TARGET	EMAP	1993	MILLSTONE CR.	NORTHAPPS	NSS-APP	BRADFORD	41.66547	76.51676	3	FLOWING	Y	Y	Y	Y	Y
PA509S	TARGET	EMAP	1993	NONAME TRIB EAST BRANCH		NSS-APP	LACKAWANNA	41.30224	75.44573	1	FLOWING	Y	Y	Y	Y	Y
PA510S	TARGET	EMAP	1993	LAUREL RUN		NSS-APP	CENTRE	41.10133	78.08169	1	FLOWING	Y	Y	Y	Y	Y
PA513S	TARGET	EMAP	1993	WOLF CR.	RIDGE	67d	LYCOMING	41.21731	76.80550	3	FLOWING	Y	Y	Y	Y	Y
PA516S	TARGET	EMAP	1993	TIPTON RUN		NSS-APP	BLAIR	40.68346	78.33228	2	FLOWING	Y	Y	Y	Y	Y
PA517S	TARGET	EMAP	1993	NONAME TRIB GEORGES CR.		67d	BEDFORD	40.19388	78.59230	1	FLOWING	Y	Y	N	Y	Y
PA518S	TARGET	EMAP	1993	LAUREL RUN (SHEAFFER VALLEY)		67a	PERRY	40.33531	77.34540	2	FLOWING	Y	Y	Y	Y	Y
PA519S	TARGET	EMAP	1993	BOW CR.		67b	DAUPHIN	40.39046	76.68951	1	FLOWING	Y	Y	Y	Y	Y
PA522S	TARGET	EMAP	1993	NONAME TRIB TO TRIB LITTLE TONOLOWAY CR.		67b	FULTON	39.83982	78.24806	1	FLOWING	Y	Y	N	Y	Y
PA523S	TARGET	EMAP	1993	BELL RUN	NORTHAPPS	NSS-APP	MCKEAN	41.95601	78.23433	3	FLOWING	Y	Y	Y	Y	Y
PA524S	TARGET	EMAP	1993	E. BR. SPRING CR.		APP-PLAT	WARREN	41.81760	79.58672	3	FLOWING	Y	Y	Y	Y	Y
PA525S	TARGET	EMAP	1993	COBBS RUN		APP-PLAT	WARREN	41.81394	79.56367	1	FLOWING	Y	Y	Y	Y	Y
PA526S	TARGET	EMAP	1993	AJAX RUN	WESTAPPS	APP-PLAT	VENANGO	41.34690	79.80471	1	FLOWING	Y	Y	N	Y	Y
PA528S	TARGET	EMAP	1993	MAPLE CR.		NSS-APP	FOREST	41.44212	79.16454	2	FLOWING	Y	Y	Y	Y	Y
PA529S	TARGET	EMAP	1993	STUMP CR.		NSS-APP	CLEARFIELD	41.04169	78.75870	2	FLOWING	Y	Y	Y	Y	Y
PA530S	TARGET	EMAP	1993	YELLOW CR.		NSS-APP	INDIANA	40.60826	78.97429	3	FLOWING	Y	Y	Y	Y	Y
PA531S	TARGET	EMAP	1993	POWDERMILL RUN		NSS-APP	WESTMORELAND	40.14105	79.26390	2	FLOWING	Y	Y	Y	Y	Y
PA532S	TARGET	EMAP	1993	PIKE RUN		APP-PLAT	WASHINGTON	40.06584	79.90139	3	FLOWING	Y	Y	Y	Y	Y
PA533S	TARGET	EMAP	1993	POTATO GARDEN RUN		APP-PLAT	ALLEGHENY	40.47343	80.33095	2	FLOWING	Y	Y	N	Y	Y
PA534S	TARGET	EMAP	1993	NONAME TRIB LAKE ARTHUR		APP-PLAT	BUTLER	40.92008	80.06435	1	FLOWING	Y	Y	Y	Y	Y
PA535S	TARGET	TIME	1993	TINKWIG CR		NSS-APP	PIKE	41.52519	75.12435	1	INTERUPT	Y	N	N	N	N
PA537S	TARGET	TIME	1993	MUD POND RUN	NORTHAPPS	NSS-APP	PIKE	41.25989	75.17310	2	FLOWING	Y	N	N	Y	N
PA538S	TARGET	REMAP	1993	LYON CR		67b	LEHIGH	40.64249	75.66546	3	FLOWING	Y	Y	N	Y	N
PA539S	TARGET	REMAP	1993	NONAME TRIB EAST BRANCH MONOCACY		67a	NORTHAMPTON	40.75313	75.34809	1	FLOWING	Y	Y	N	Y	N
PA540S	TARGET	TIME	1993	WILDCAT RUN		NSS-APP	SUSQUEHANNA	41.92455	75.51362	1	FLOWING	Y	N	N	Y	N
PA541S	TARGET	TIME	1993	WEBIER CR		NSS-APP	BRADFORD	41.75246	76.85274	1	INTERUPT	Y	N	N	Y	N
PA544S	TARGET	TIME	1993	APPLE CR		NSS-APP	BRADFORD	41.89739	76.61705	1	FLOWING	Y	N	N	Y	N
PA545S	TARGET	TIME	1993	JOHNSON CR		NSS-APP	BRADFORD	41.84790	76.28932	3	FLOWING	Y	N	N	Y	N

Appendix Table 2. Station locations, ecoregion designation, and parameters measured.

STRM_ID	SITECLS	STUDY	YEAR	STRMNAME	ECOAREA	ECOREG	COUNTY	LAT_DD	LON_DD	ORD	FLOWSITE	BENTH RBPHAB	FISH	FISH TISS	STRM CHEM	PHAB DO/TEMP
PA546S	TARGET	REMAP	1993	BLACK CR		67b	LUZERNE	40.99868	76.17676	3	FLOWING	Y	Y	N	Y	N
PA547S	TARGET	TIME	1993	CREASY CR		NSS-APP	LUZERNE	41.09616	75.81951	1	FLOWING	Y	N	N	Y	N
PA548S	TARGET	TIME	1993	BLOODY RUN	NORTHAPPS	NSS-APP	SULLIVAN	41.32730	76.44073	1	FLOWING	Y	N	N	Y	N
PA549S	TARGET	REMAP	1993	NONAME TRIB LITTLE FISHING CR		67b	COLUMBIA	41.05998	76.50936	1	FLOWING	Y	Y	N	Y	N
PA550S	TARGET	TIME	1993	NONAME TRIB LAKAWANNA		67d	WAYNE	41.59761	75.45181	1	INTERUPT	Y	Y	N	N	N
PA552S	TARGET	REMAP	1993	NONAME TRIB SUSQUEHANNA		67b	NORTHUMBERLA	40.90988	76.71279	1	INTERUPT	Y	Y	N	Y	N
PA553S	TARGET	TIME	1993	CHEST CR		NSS-APP	CAMBRIA	40.71271	78.68134	3	FLOWING	Y	N	N	Y	N
PA554S	TARGET	TIME	1993	WILSON RUN		NSS-APP	CLEARFIELD	40.82680	78.66652	2	FLOWING	Y	N	N	Y	N
PA555S	TARGET	TIME	1993	BEAVER RUN		NSS-APP	CLEARFIELD	40.77370	78.77733	3	FLOWING	Y	N	N	Y	N
PA557S	TARGET	TIME	1993	LAUREL RUN		NSS-APP	CLEARFIELD	40.97858	78.44218	1	FLOWING	Y	N	N	Y	N
PA558S	TARGET	TIME	1993	HUNTS RUN		NSS-APP	CAMERON	41.45521	78.17126	3	FLOWING	Y	N	N	Y	N
PA559S	TARGET	TIME	1993	MEDIX RUN		NSS-APP	ELK	41.26917	78.40376	3	FLOWING	Y	N	N	Y	N
PA561S	TARGET	TIME	1993	SMITH RUN	NORTHAPPS	NSS-APP	CLINTON	41.27149	77.87190	1	FLOWING	Y	N	N	Y	N
PA562S	TARGET	TIME	1993	SLATE RUN		NSS-APP	LYCOMING	41.50490	77.52131	3	FLOWING	Y	N	N	Y	N
PA563S	TARGET	TIME	1993	NONAME TRIB MILL RUN		NSS-APP	TIOGA	41.77149	77.50138	1	FLOWING	Y	N	N	Y	N
PA564S	TARGET	TIME	1993	NONAME TRIB TO NONAME TRIB PINE CR		NSS-APP	POTTER	41.84134	77.83360	1	FLOWING	Y	N	N	Y	N
PA565S	TARGET	TIME	1993	WHITE DEER CR		67c	UNION	41.02258	77.15089	2	FLOWING	Y	Y	N	Y	N
PA566S	TARGET	TIME	1993	WOLF RUN		NSS-APP	LYCOMING	41.39454	77.09641	1	FLOWING	Y	N	N	Y	N
PA567S	TARGET	TIME	1993	ROCK RUN		NSS-APP	LYCOMING	41.54232	76.85027	2	FLOWING	Y	N	N	Y	N
PA568S	TARGET	TIME	1993	HUNTERS RUN		67c	PERRY	40.52921	76.98879	2	FLOWING	Y	Y	N	Y	N
PA569S	TARGET	REMAP	1993	SCHWABEN CR		67b	NORTHUMBERLA	40.72123	76.72951	3	FLOWING	Y	Y	N	Y	N
PA570S	TARGET	REMAP	1993	MAHANTANGO		67b	SCHUYLKILL	40.66997	76.63285	3	FLOWING	Y	Y	N	Y	N
PA573S	TARGET	REMAP	1993	MURRAY RUN		67b	HUNTINGDON	40.55225	77.96221	2	FLOWING	Y	Y	N	Y	N
PA574S	TARGET	REMAP	1993	COVE CR		67a	BEDFORD	39.90439	78.53194	2	FLOWING	Y	Y	N	Y	N
PA575S	TARGET	TIME	1993	FRENCH RUN		67d	BEDFORD	40.04478	78.29422	2	FLOWING	Y	Y	N	Y	N
PA576S	TARGET	REMAP	1993	WILLOW RUN		67b	JUNIATA	40.39678	77.64310	1	FLOWING	Y	Y	N	Y	N
PA577S	TARGET	TIME	1993	NONAME TRIB LAUREL FORK - WISHART SWAMP	CENTAPPS	NSS-APP	FULTON	40.08523	78.19007	1	FLOWING	Y	N	N	Y	N
PA579S	TARGET	TIME	1993	NONAME TRIB CLIPPINGERS RUN		67c	FRANKLIN	40.13365	77.63966	1	FLOWING	Y	N	N	Y	N
PA580S	TARGET	REMAP	1993	NONAME TRIB CONODOGUINET CR		67b	CUMBERLAND	40.26504	76.99959	1	FLOWING	Y	Y	N	Y	N
PA582S	TARGET	REMAP	1993	NONAME TRIB UPPER LITTLE SWATARA CR		67b	SCHUYLKILL	40.59294	76.31336	1	FLOWING	Y	Y	N	Y	N
PA583S	TARGET	TIME	1993	OPOSSUM CR		66a	ADAMS	39.98985	77.25261	3	FLOWING	Y	N	N	Y	N
PA584S	TARGET	REMAP	1993	NONAME TRIB PATTERSON RUN		67b	FULTON	39.99618	77.98662	1	FLOWING	Y	Y	N	Y	N
PA585S	TARGET	TIME	1993	MARVIN CR		NSS-APP	MCKEAN	41.79748	78.46567	3	FLOWING	Y	N	N	Y	N
PA587S	TARGET	TIME	1993	NONAME TRIB HUBERT RUN		NSS-APP	MCKEAN	41.67248	78.80380	1	FLOWING	N	N	N	Y	N
PA588S	TARGET	TIME	1993	EAST SANDY CR		NSS-APP	CLARION	41.33208	79.50517	2	FLOWING	Y	N	N	Y	N
PA589S	TARGET	TIME	1993	HEDGEHOG RUN	NORTHAPPS	NSS-APP	WARREN	41.78934	79.24826	1	FLOWING	Y	N	N	Y	N
PA590S	TARGET	TIME	1993	CANOE CR		NSS-APP	CLARION	41.22884	79.51871	3	FLOWING	Y	N	N	Y	N
PA591S	TARGET	TIME	1993	TOBY CR		NSS-APP	CLARION	41.27065	79.35850	3	FLOWING	Y	N	N	Y	N
PA592S	TARGET	TIME	1993	NORTH BRANCH LITTLE CONEMAUGH		NSS-APP	CAMBRIA	40.45509	78.68429	2	FLOWING	Y	N	N	Y	N
PA593S	TARGET	TIME	1993	AULTMANS RUN		NSS-APP	INDIANA	40.48245	79.31067	3	FLOWING	Y	N	N	Y	N
PA594S	TARGET	TIME	1993	BENS CR		NSS-APP	SOMERSET	40.28380	78.93134	3	FLOWING	Y	N	N	Y	N
PA595S	TARGET	TIME	1993	NONAME TRIB CLEAR RUN		NSS-APP	SOMERSET	40.04538	78.81057	1	FLOWING	Y	N	N	Y	N
PA597S	TARGET	TIME	1993	NONAME TRIB CASSELMAN		NSS-APP	SOMERSET	39.87383	79.26331	1	FLOWING	Y	N	N	Y	N
PA598S	TARGET	TIME	1993	LIMESTONE RUN	CENTAPPS	NSS-APP	FAYETTE	39.91997	79.57040	1	FLOWING	Y	N	N	Y	N
PA750S	TARGET	EMAP	1994	NNT WEST BR BEAVER KILL	NORTHAPPS	NSS-APP	WAYNE	41.95000	75.36680	2	FLOWING	Y	Y	Y	Y	Y
PA751S	TARGET	EMAP	1994	PARADISE CR	NORTHAPPS	NSS-APP	MONROE	41.10110	75.26710	3	FLOWING	Y	Y	Y	Y	Y
PA752S	TARGET	EMAP	1994	NORTH BR PINE RUN	PIED/CP	PIED/CP	BUCKS	40.29180	75.20590	2	FLOWING	Y	Y	Y	Y	Y
PA753S	TARGET	EMAP	1994	BEAVER RUN	PIED/CP	PIED/CP	BERKS	40.22510	75.85400	1	FLOWING	Y	Y	Y	Y	Y
PA755S	TARGET	EMAP	1994	BIRCH CR	NORTHAPPS	NSS-APP	SULLIVAN	41.48090	76.34980	2	FLOWING	Y	Y	Y	Y	Y
PA756S	TARGET	EMAP	1994	TUNNIS RUN	RIDGE	67c	CENTRE	41.00280	77.26090	1	FLOWING	Y	Y	Y	Y	Y
PA757S	TARGET	EMAP	1994	LITTLE WICONISOCO CR	VALLEY	67b	DAUPHIN	40.57510	76.88850	2	FLOWING	Y	Y	Y	Y	Y
PA759S	TARGET	EMAP	1994	HAMMER HALLOW	RIDGE	67c	JUNIATA	40.54390	77.47950	1	FLOWING	Y	Y	N	Y	Y
PA760S	TARGET	EMAP	1994	SKINNER GAP	RIDGE	67c	FRANKLIN	40.04870	77.76600	1	INTERUPT	Y	Y	Y	Y	Y
PA761S	TARGET	EMAP	1994	NNT OCTORARO CR	PIED/CP	PIED/CP	LANCASTER	39.77010	76.07810	1	FLOWING	Y	Y	Y	Y	Y

Appendix Table 2. Station locations, ecoregion designation, and parameters measured.

STRM_ID	SITECLS	STUDY	YEAR	STRMNAME	ECOAREA	ECOREG	COUNTY	LAT_DD	LON_DD	ORD	FLOWSITE	BENTH RBPHAB	FISH	FISH TISS	STRM CHEM	PHAB DO/TEMP
PA546S	TARGET	REMAP	1993	BLACK CR		67b	LUZERNE	40.99868	76.17676	3	FLOWING	Y	Y	N	Y	N
PA547S	TARGET	TIME	1993	CREASY CR		NSS-APP	LUZERNE	41.09616	75.81951	1	FLOWING	Y	N	N	Y	N
PA548S	TARGET	TIME	1993	BLOODY RUN	NORTHAPPS	NSS-APP	SULLIVAN	41.32730	76.44073	1	FLOWING	Y	N	N	Y	N
PA549S	TARGET	REMAP	1993	NONAME TRIB LITTLE FISHING CR		67b	COLUMBIA	41.05998	76.50936	1	FLOWING	Y	Y	N	Y	N
PA550S	TARGET	TIME	1993	NONAME TRIB LAKAWANNA		67d	WAYNE	41.59761	75.45181	1	INTERUPT	Y	Y	N	N	N
PA552S	TARGET	REMAP	1993	NONAME TRIB SUSQUEHANNA		67b	NORTHUMBERLA	40.90988	76.71279	1	INTERUPT	Y	Y	N	Y	N
PA553S	TARGET	TIME	1993	CHEST CR		NSS-APP	CAMBRIA	40.71271	78.68134	3	FLOWING	Y	N	N	Y	N
PA554S	TARGET	TIME	1993	WILSON RUN		NSS-APP	CLEARFIELD	40.82680	78.66652	2	FLOWING	Y	N	N	Y	N
PA555S	TARGET	TIME	1993	BEAVER RUN		NSS-APP	CLEARFIELD	40.77370	78.77733	3	FLOWING	Y	N	N	Y	N
PA557S	TARGET	TIME	1993	LAUREL RUN		NSS-APP	CLEARFIELD	40.97858	78.44218	1	FLOWING	Y	N	N	Y	N
PA558S	TARGET	TIME	1993	HUNTS RUN		NSS-APP	CAMERON	41.45521	78.17126	3	FLOWING	Y	N	N	Y	N
PA559S	TARGET	TIME	1993	MEDIX RUN		NSS-APP	ELK	41.26917	78.40376	3	FLOWING	Y	N	N	Y	N
PA561S	TARGET	TIME	1993	SMITH RUN	NORTHAPPS	NSS-APP	CLINTON	41.27149	77.87190	1	FLOWING	Y	N	N	Y	N
PA562S	TARGET	TIME	1993	SLATE RUN		NSS-APP	LYCOMING	41.50490	77.52131	3	FLOWING	Y	N	N	Y	N
PA563S	TARGET	TIME	1993	NONAME TRIB MILL RUN		NSS-APP	TIOGA	41.77149	77.50138	1	FLOWING	Y	N	N	Y	N
PA564S	TARGET	TIME	1993	NONAME TRIB TO NONAME TRIB PINE CR		NSS-APP	POTTER	41.84134	77.83360	1	FLOWING	Y	N	N	Y	N
PA565S	TARGET	TIME	1993	WHITE DEER CR		67c	UNION	41.02258	77.15089	2	FLOWING	Y	Y	N	Y	N
PA566S	TARGET	TIME	1993	WOLF RUN		NSS-APP	LYCOMING	41.39454	77.09641	1	FLOWING	Y	N	N	Y	N
PA567S	TARGET	TIME	1993	ROCK RUN		NSS-APP	LYCOMING	41.54232	76.85027	2	FLOWING	Y	N	N	Y	N
PA568S	TARGET	TIME	1993	HUNTERS RUN		67c	PERRY	40.52921	76.98879	2	FLOWING	Y	Y	N	Y	N
PA569S	TARGET	REMAP	1993	SCHWABEN CR		67b	NORTHUMBERLA	40.72123	76.72951	3	FLOWING	Y	Y	N	Y	N
PA570S	TARGET	REMAP	1993	MAHANTANGO		67b	SCHUYLKILL	40.66997	76.63285	3	FLOWING	Y	Y	N	Y	N
PA573S	TARGET	REMAP	1993	MURRAY RUN		67b	HUNTINGDON	40.55225	77.96221	2	FLOWING	Y	Y	N	Y	N
PA574S	TARGET	REMAP	1993	COVE CR		67a	BEDFORD	39.90439	78.53194	2	FLOWING	Y	Y	N	Y	N
PA575S	TARGET	TIME	1993	FRENCH RUN		67d	BEDFORD	40.04478	78.29422	2	FLOWING	Y	Y	N	Y	N
PA576S	TARGET	REMAP	1993	WILLOW RUN		67b	JUNIATA	40.39678	77.64310	1	FLOWING	Y	Y	N	Y	N
PA577S	TARGET	TIME	1993	NONAME TRIB LAUREL FORK - WISHART SWAMP	CENTAPPS	NSS-APP	FULTON	40.08523	78.19007	1	FLOWING	Y	N	N	Y	N
PA579S	TARGET	TIME	1993	NONAME TRIB CLIPPINGERS RUN		67c	FRANKLIN	40.13365	77.63966	1	FLOWING	Y	N	N	Y	N
PA580S	TARGET	REMAP	1993	NONAME TRIB CONODOGUINET CR		67b	CUMBERLAND	40.26504	76.99959	1	FLOWING	Y	Y	N	Y	N
PA582S	TARGET	REMAP	1993	NONAME TRIB UPPER LITTLE SWATARA CR		67b	SCHUYLKILL	40.59294	76.31336	1	FLOWING	Y	Y	N	Y	N
PA583S	TARGET	TIME	1993	OPOSSUM CR		66a	ADAMS	39.98985	77.25261	3	FLOWING	Y	N	N	Y	N
PA584S	TARGET	REMAP	1993	NONAME TRIB PATTERSON RUN		67b	FULTON	39.99618	77.98662	1	FLOWING	Y	Y	N	Y	N
PA585S	TARGET	TIME	1993	MARVIN CR		NSS-APP	MCKEAN	41.79748	78.46567	3	FLOWING	Y	N	N	Y	N
PA587S	TARGET	TIME	1993	NONAME TRIB HUBERT RUN		NSS-APP	MCKEAN	41.67248	78.80380	1	FLOWING	N	N	N	Y	N
PA588S	TARGET	TIME	1993	EAST SANDY CR		NSS-APP	CLARION	41.33208	79.50517	2	FLOWING	Y	N	N	Y	N
PA589S	TARGET	TIME	1993	HEDGEHOG RUN	NORTHAPPS	NSS-APP	WARREN	41.78934	79.24826	1	FLOWING	Y	N	N	Y	N
PA590S	TARGET	TIME	1993	CANOE CR		NSS-APP	CLARION	41.22884	79.51871	3	FLOWING	Y	N	N	Y	N
PA591S	TARGET	TIME	1993	TOBY CR		NSS-APP	CLARION	41.27065	79.35850	3	FLOWING	Y	N	N	Y	N
PA592S	TARGET	TIME	1993	NORTH BRANCH LITTLE CONEMAUGH		NSS-APP	CAMBRIA	40.45509	78.68429	2	FLOWING	Y	N	N	Y	N
PA593S	TARGET	TIME	1993	AULTMANS RUN		NSS-APP	INDIANA	40.48245	79.31067	3	FLOWING	Y	N	N	Y	N
PA594S	TARGET	TIME	1993	BENS CR		NSS-APP	SOMERSET	40.28380	78.93134	3	FLOWING	Y	N	N	Y	N
PA595S	TARGET	TIME	1993	NONAME TRIB CLEAR RUN		NSS-APP	SOMERSET	40.04538	78.81057	1	FLOWING	Y	N	N	Y	N
PA597S	TARGET	TIME	1993	NONAME TRIB CASSELMAN		NSS-APP	SOMERSET	39.87383	79.26331	1	FLOWING	Y	N	N	Y	N
PA598S	TARGET	TIME	1993	LIMESTONE RUN	CENTAPPS	NSS-APP	FAYETTE	39.91997	79.57040	1	FLOWING	Y	N	N	Y	N
PA750S	TARGET	EMAP	1994	NNT WEST BR BEAVER KILL	NORTHAPPS	NSS-APP	WAYNE	41.95000	75.36680	2	FLOWING	Y	Y	Y	Y	Y
PA751S	TARGET	EMAP	1994	PARADISE CR	NORTHAPPS	NSS-APP	MONROE	41.10110	75.26710	3	FLOWING	Y	Y	Y	Y	Y
PA752S	TARGET	EMAP	1994	NORTH BR PINE RUN	PIED/CP	PIED/CP	BUCKS	40.29180	75.20590	2	FLOWING	Y	Y	Y	Y	Y
PA753S	TARGET	EMAP	1994	BEAVER RUN	PIED/CP	PIED/CP	BERKS	40.22510	75.85400	1	FLOWING	Y	Y	Y	Y	Y
PA755S	TARGET	EMAP	1994	BIRCH CR	NORTHAPPS	NSS-APP	SULLIVAN	41.48090	76.34980	2	FLOWING	Y	Y	Y	Y	Y
PA756S	TARGET	EMAP	1994	TUNNIS RUN	RIDGE	67c	CENTRE	41.00280	77.26090	1	FLOWING	Y	Y	Y	Y	Y
PA757S	TARGET	EMAP	1994	LITTLE WICONISOCO CR	VALLEY	67b	DAUPHIN	40.57510	76.88850	2	FLOWING	Y	Y	Y	Y	Y
PA759S	TARGET	EMAP	1994	HAMMER HALLOW	RIDGE	67c	JUNIATA	40.54390	77.47950	1	FLOWING	Y	Y	N	Y	Y
PA760S	TARGET	EMAP	1994	SKINNER GAP	RIDGE	67c	FRANKLIN	40.04870	77.76600	1	INTERUPT	Y	Y	Y	Y	Y
PA761S	TARGET	EMAP	1994	NNT OCTORARO CR	PIED/CP	PIED/CP	LANCASTER	39.77010	76.07810	1	FLOWING	Y	Y	Y	Y	Y

Appendix Table 2. Station locations, ecoregion designation, and parameters measured.

STRM_ID	SITECLS	STUDY	YEAR	STRMNAME	ECOAREA	ECOREG	COUNTY	LAT_DD	LON_DD	ORD	FLOWSITE	BENTH RBPHAB	FISH	FISH TISS	STRM CHEM	PHAB DO/TEMP
PA828S	TARGET	TIME	1994	COON CR	WESTAPPS	NSS-APP	FOREST	41.46102	79.35710	3	FLOWING	Y	N	N	Y	N
PA829S	TARGET	TIME	1994	BIG RUN	NORTHAPPS	NSS-APP	ELK	41.43973	78.95430	3	FLOWING	Y	N	N	Y	N
PA831S	TARGET	TIME	1994	TOBY CR	NORTHAPPS	NSS-APP	CLARION	41.25590	79.36920	3	FLOWING	Y	N	N	Y	N
PA832S	TARGET	TIME	1994	STRAIGHT CR	NORTHAPPS	NSS-APP	ELK	41.59958	78.47720	1	FLOWING	Y	N	N	Y	N
PA833S	TARGET	TIME	1994	COLEMAN RUN	NORTHAPPS	NSS-APP	FOREST	41.35462	79.17630	2	FLOWING	Y	N	N	Y	N
PA835S	TARGET	TIME	1994	NORTH BR BLACKLICK	CENTAPPS	NSS-APP	CAMBRIA	40.58463	78.80420	2	FLOWING	Y	N	N	Y	N
PA836S	TARGET	TIME	1994	NNT QUEMAHONING CR	CENTAPPS	NSS-APP	SOMERSET	40.14839	79.03950	1	FLOWING	Y	N	N	Y	N
PA837S	TARGET	TIME	1994	KOOSER RUN	CENTAPPS	NSS-APP	SOMERSET	40.06398	79.23610	2	FLOWING	Y	N	N	Y	N
PA839S	TARGET	TIME	1994	NNT CASSELMAN R	CENTAPPS	NSS-APP	SOMERSET	39.76941	79.06580	2	FLOWING	Y	N	N	Y	N
PA840S	TARGET	TIME	1994	WILLOW CR	NORTHAPPS	NSS-APP	MCKEAN	41.98640	78.91340	3	FLOWING	Y	N	N	Y	N
PA842S	TARGET	TIME+	1994	CARLEY BROOK	NORTHAPPS	NSS-APP	WAYNE	41.56130	75.24570	3	FLOWING	Y	N	N	Y	N
PA844S	TARGET	TIME+	1994	SNAKE CR	NORTHAPPS	NSS-APP	SUSQUEHANNA	41.90770	75.84540	3	FLOWING	Y	N	N	Y	N
PA846S	TARGET	TIME+	1994	NNT BEAR RUN	CENTAPPS	NSS-APP	CLEARFIELD	40.88700	78.77610	1	FLOWING	Y	N	N	Y	N
PA847S	TARGET	TIME+	1994	WYKOFF RUN	NORTHAPPS	NSS-APP	CAMERON	41.30640	78.08970	3	FLOWING	Y	N	N	Y	N
PA848S	TARGET	TIME+	1994	RIGHT FORK HEVNER RUN	NORTHAPPS	NSS-APP	CLINTON	41.39530	77.87330	1	FLOWING	Y	N	N	Y	N
PA849S	TARGET	TIME+	1994	BEAR RUN	RIDGE	67c	CLINTON	40.99650	77.45740	1	FLOWING	Y	N	N	Y	N
PA850S	TARGET	TIME+	1994	LYMAN RUN	NORTHAPPS	NSS-APP	POTTER	41.74240	77.84040	1	FLOWING	Y	N	N	Y	N
PA852S	TARGET	TIME+	1994	DRY RUN	NORTHAPPS	NSS-APP	LYCOMING	41.40940	76.79130	1	FLOWING	Y	N	N	Y	N
PA853S	TARGET	TIME+	1994	SUGAR GROVE RUN	RIDGE	67d	HUNTINGDON	40.47520	77.93890	2	FLOWING	Y	N	N	Y	N
PA854S	TARGET	TIME+	1994	ALLEGHENY PORTAGE CR	NORTHAPPS	NSS-APP	MCKEAN	41.75960	78.25600	3	FLOWING	Y	N	N	Y	N
PA855S	TARGET	TIME+	1994	FOOLS CR	NORTHAPPS	NSS-APP	WARREN	41.63720	79.14070	1	FLOWING	Y	N	N	Y	N
PA856S	TARGET	TIME+	1994	BEER RUN	NORTHAPPS	NSS-APP	JEFFERSON	41.27010	79.18370	1	FLOWING	Y	N	N	Y	N
PA857S	TARGET	TIME+	1994	BEAR RUN	CENTAPPS	NSS-APP	FAYETTE	39.89870	79.46280	2	FLOWING	Y	N	N	Y	N
VA507S	TARGET	EMAP	1993	ROCKY BRANCH		67c	BOTETOURT	37.49726	79.97843	1	FLOWING	Y	Y	Y	Y	Y
VA508S	TARGET	EMAP	1993	NONAME TRIB LEFT PRONG		67b	BATH	37.94856	79.80891	1	INTERUPT	Y	N	N	Y	Y
VA509S	TARGET	EMAP	1993	HUNTING CR.		66a	BEDFORD	37.54025	79.39001	2	FLOWING	Y	Y	Y	Y	Y
VA515S	TARGET	EMAP	1993	DAN RIVER		66a	PATRICK	36.58553	80.44366	3	FLOWING	Y	Y	Y	Y	Y
VA522S	TARGET	EMAP	1993	BRUSH CR.		66c	FLOYD	37.03338	80.26999	1	FLOWING	Y	Y	Y	Y	Y
VA523S	TARGET	EMAP	1993	MCGAVOCK CR.	VALLEY	67a	WYTHE	36.95970	80.84441	1	FLOWING	Y	Y	Y	Y	Y
VA524S	TARGET	EMAP	1993	NONAME TRIB STONY CR.		67c	GILES	37.42337	80.62978	1	INTERUPT	Y	Y	N	Y	Y
VA525S	TARGET	EMAP	1993	DISMAL CR.		APP-PLAT	BUCHANAN	37.24123	81.87161	3	FLOWING	Y	Y	Y	Y	Y
VA526S	TARGET	EMAP	1993	BEARPEN BRANCH		APP-PLAT	DICKENSON	37.20131	82.48649	2	FLOWING	Y	Y	Y	Y	Y
VA527S	TARGET	EMAP	1993	NONAME TRIB BRUMLEY CR. (4TH ORD+C131)		67c	WASHINGTON	36.79876	82.03284	2	FLOWING	Y	Y	Y	Y	Y
VA528S	TARGET	EMAP	1993	NONAME TRIB BEAR CR.		67d	SMYTH	36.90037	81.44667	1	INTERUPT	Y	Y	N	Y	Y
VA529S	TARGET	EMAP	1993	HARDY CR.		67a	LEE	36.64308	83.24444	3	FLOWING	Y	Y	Y	Y	Y
VA530S	TARGET	EMAP	1993	DRY RUN		66b	WARREN	38.97795	78.06522	1	FLOWING	Y	Y	Y	Y	Y
VA531S	TARGET	EMAP	1993	RAGGED RUN	BLUERIDGE	66a	MADISON	38.53744	78.30582	1	FLOWING	Y	Y	Y	Y	Y
VA532S	TARGET	EMAP	1993	NONAME TRIB COOKS CR.		67a	ROCKINGHAM	38.46348	78.94933	1	INTERUPT	N	N	N	Y	Y
VA535S	TARGET	EMAP	1993	NONAME TRIB CHRISTIANS CR.		67a	AUGUSTA	38.02889	79.16039	2	FLOWING	Y	Y	Y	Y	Y
VA536S	TARGET	REMAP	1993	SLATE RUN		67b	FREDERICK	39.24414	78.04718	1	FLOWING	Y	Y	N	Y	N
VA537S	TARGET	REMAP	1993	REDBUD RUN		67a	FREDERICK	39.21733	78.15602	1	FLOWING	Y	Y	N	Y	N
VA538S	TARGET	TIME	1993	NORTH		67d	AUGUSTA	38.35398	79.25980	2	FLOWING	Y	Y	N	Y	N
VA539S	TARGET	REMAP	1993	MIDDLE		67b	AUGUSTA	38.19600	78.96717	3	FLOWING	Y	Y	N	Y	N
VA540S	TARGET	REMAP	1993	MIDDLE		67b	AUGUSTA	38.18911	78.96935	3	FLOWING	Y	Y	N	Y	N
VA541S	TARGET	REMAP	1993	MOFFET CR		67a	AUGUSTA	38.29256	79.12966	3	FLOWING	Y	Y	N	Y	N
VA542S	TARGET	REMAP	1993	CHRISTIANS CR		67b	AUGUSTA	38.18482	78.95917	3	FLOWING	Y	Y	N	Y	N
VA543S	TARGET	REMAP	1993	PORTERFIELD RUN		67a	AUGUSTA	38.13456	78.86486	2	FLOWING	Y	Y	N	Y	N
VA544S	TARGET	REMAP	1993	NONAME TRIB FLINT RUN		67a	WARREN	38.82909	78.29518	1	FLOWING	Y	Y	N	Y	N
VA546S	TARGET	REMAP	1993	MILL RUN		67a	SHENANDOAH	38.87671	78.37684	1	FLOWING	Y	Y	N	Y	N
VA547S	TARGET	REMAP	1993	NONAME TRIB PASSAGE CR		67a	SHENANDOAH	38.87124	78.39638	1	FLOWING	Y	Y	N	Y	N
VA548S	TARGET	TIME	1993	NONAME TRIB GAP CR		67c	SHENANDOAH	38.69907	78.59636	1	INTERUPT	Y	N	N	Y	N
VA549S	TARGET	TIME	1993	BACK CR		67d	BATH	38.24607	79.76332	3	FLOWING	Y	Y	N	Y	N
VA550S	TARGET	TIME	1993	NONAME TRIB CRAIG CR		67c	MONTGOMERY	37.35155	80.31484	1	FLOWING	Y	Y	N	Y	N
VA551S	TARGET	TIME	1993	THORNY BRANCH		67d	ALLEGHANY	37.83408	80.10802	1	FLOWING	Y	N	N	Y	N

Appendix Table 2. Station locations, ecoregion designation, and parameters measured.

STRM_ID	SITECLS	STUDY	YEAR	STRMNAME	ECOAREA	ECOREG	COUNTY	LAT_DD	LON_DD	ORD	FLOWSITE	BENTH RBPHAB	FISH	FISH TISS	STRM CHEM	PHAB DO/TEMP
VA553S	TARGET	TIME	1993	NONAME TRIB JAMES		67c	BOTETOURT	37.66660	79.78663	1	FLOWING	Y	N	N	Y	N
VA554S	TARGET	REMAP	1993	MILL CR		67b	BATH	38.15891	79.47297	1	FLOWING	Y	Y	N	Y	N
VA555S	TARGET	TIME	1993	LITTLE MILL CR	RIDGE	67c	BATH	38.08011	79.49946	1	FLOWING	Y	Y	N	Y	N
VA556S	TARGET	REMAP	1993	WHISTLE CR		67a	ROCKBRIDGE	37.81872	79.49139	1	FLOWING	Y	Y	N	Y	N
VA558S	TARGET	REMAP	1993	NORTH FORK ROANOKE		67a	MONTGOMERY	37.26404	80.32911	3	FLOWING	Y	Y	N	Y	N
VA559S	TARGET	TIME	1993	BACK CR		66a	ROANOKE	37.17883	79.93636	3	FLOWING	Y	N	N	Y	N
VA560S	TARGET	REMAP	1993	BACK CR		67b	ROANOKE	37.20231	80.02563	3	FLOWING	Y	Y	N	Y	N
VA561S	TARGET	REMAP	1993	NONAME TRIB NORTH FORK GOOSE CR		67b	BEDFORD	37.44359	79.69871	1	FLOWING	Y	Y	N	Y	N
VA562S	TARGET	TIME	1993	BURKS FORK		66c	FLOYD	36.80744	80.53991	3	FLOWING	Y	N	N	Y	N
VA563S	TARGET	REMAP	1993	CONNELLYS RUN		67a	MONTGOMERY	37.11020	80.52367	1	FLOWING	Y	Y	N	Y	N
VA564S	TARGET	TIME	1993	EAST FORK LITTLE REED IS CR		66c	CARROLL	36.72837	80.74063	3	FLOWING	Y	N	N	Y	N
VA565S	TARGET	REMAP	1993	THORN CR		67b	WYTHE	36.85090	81.14289	1	FLOWING	Y	Y	N	Y	N
VA566S	TARGET	TIME	1993	JONES BRANCH		66c	GRAYSON	36.60125	81.45621	1	FLOWING	Y	N	N	Y	N
VA567S	TARGET	TIME	1993	JONES BRANCH		66b	GRAYSON	36.79966	81.04659	1	FLOWING	Y	N	N	Y	N
VA568S	TARGET	REMAP	1993	DING BRANCH		67b	BLAND	37.21020	80.95126	1	FLOWING	Y	Y	N	Y	N
VA569S	TARGET	REMAP	1993	COVE CR		67a	WASHINGTON	36.62790	82.28185	1	FLOWING	Y	Y	N	Y	N
VA570S	TARGET	REMAP	1993	BACK FORK MILL CR		67b	SMYTH	36.71359	81.65757	1	FLOWING	Y	Y	N	Y	N
VA571S	TARGET	REMAP	1993	LITTLE		67a	TAZEWELL	37.02833	81.77641	3	FLOWING	Y	Y	N	Y	N
VA572S	TARGET	REMAP	1993	LITTLE		67a	TAZEWELL	37.02331	81.74068	3	FLOWING	Y	Y	N	Y	N
VA573S	TARGET	REMAP	1993	PLUM CR		67a	TAZEWELL	37.12005	81.56266	3	FLOWING	Y	Y	N	Y	N
VA574S	TARGET	REMAP	1993	INDIAN CR		67a	RUSSELL	36.98560	81.85359	2	FLOWING	Y	Y	N	Y	N
VA751S	TARGET	EMAP	1994	ACCOTINK CR	PIED/CP	PIED/CP	FAIRFAX	38.84330	77.22420	3	FLOWING	Y	Y	Y	Y	Y
VA752S	TARGET	EMAP	1994	CARTER RUN	PIED/CP	PIED/CP	FAUQUIER	38.78690	77.87210	3	FLOWING	Y	Y	Y	Y	Y
VA753S	TARGET	EMAP	1994	NNT BURNT MILL CR	PIED/CP	PIED/CP	KING	37.59120	76.72140	1	FLOWING	Y	Y	Y	Y	Y
VA754S	TARGET	EMAP	1994	CALFPASTURE R	VALLEY	67b	AUGUSTA	38.22730	79.35450	3	FLOWING	Y	Y	Y	Y	Y
VA755S	TARGET	EMAP	1994	COLLIERS CR	VALLEY	67a	ROCKBRIDGE	37.79070	79.59750	2	FLOWING	Y	Y	Y	Y	Y
VA756S	TARGET	EMAP	1994	HOLLOWAY DRAFT	VALLEY	67b	AUGUSTA	38.21810	79.38850	1	FLOWING	Y	Y	N	Y	Y
VA757S	TARGET	EMAP	1994	NNT HATCREEK	PIED/CP	PIED/CP	NELSON	37.80390	78.95420	1	FLOWING	Y	Y	Y	Y	Y
VA758S	TARGET	EMAP	1994	MIDDLE FORK	PIED/CP	PIED/CP	FLUVANNA	37.86700	78.37070	3	FLOWING	Y	Y	Y	Y	Y
VA760S	TARGET	EMAP	1994	FORBES CR	PIED/CP	PIED/CP	BUCKINGHAM	37.41920	78.62390	1	INTERUPT	Y	N	N	Y	Y
VA761S	TARGET	EMAP	1994	NNT APPOMATTOX R	PIED/CP	PIED/CP	AMELIA	37.46760	77.97990	2	FLOWING	Y	Y	Y	Y	Y
VA762S	TARGET	EMAP	1994	NNT GLADE CR	BLUERIDGE	66a	ROANOKE	37.30670	79.85870	1	FLOWING	Y	N	N	Y	Y
VA763S	TARGET	EMAP	1994	NICHOLAS CR	PIED/CP	PIED/CP	FRANKLIN	36.86180	80.05130	3	FLOWING	Y	Y	Y	Y	Y
VA764S	TARGET	EMAP	1994	NNT POWELLS CR	PIED/CP	PIED/CP	HALIFAX	36.55350	79.01710	1	FLOWING	Y	Y	Y	Y	Y
VA765S	TARGET	EMAP	1994	MODEST CR	PIED/CP	PIED/CP	LUNENBURG	37.04160	78.21890	3	FLOWING	Y	Y	Y	Y	Y
VA767S	TARGET	EMAP	1994	BURKS FORK	BLUERIDGE	66c	CARROLL	36.78790	80.62750	3	FLOWING	Y	Y	Y	Y	Y
VA769S	TARGET	EMAP	1994	NORTH FORK KIMBERLING CR	VALLEY	67b	BLAND	37.18950	81.04560	2	FLOWING	Y	Y	Y	Y	Y
VA770S	TARGET	EMAP	1994	GUESS FORK	CENTAPPS	APP-PLAT	BUCHANAN	37.43530	82.03110	3	FLOWING	Y	Y	Y	Y	Y
VA771S	TARGET	EMAP	1994	HAMLIN BR LICK CR	CENTAPPS	APP-PLAT	RUSSELL	36.96720	82.25000	1	FLOWING	Y	Y	N	Y	Y
VA772S	TARGET	TIME	1994	WHITEMAN RUN	RIDGE	67d	HIGHLAND	38.40711	79.36230	1	FLOWING	Y	Y	N	Y	N
VA773S	TARGET	REMAP	1994	BRUSH CR	VALLEY	67b	FREDERICK	39.34830	78.23440	3	FLOWING	Y	Y	N	Y	N
VA774S	TARGET	REMAP	1994	LITTLE BRUSH CR	VALLEY	67b	FREDERICK	39.36339	78.24100	2	FLOWING	Y	Y	N	Y	N
VA775S	TARGET	REMAP	1994	MIDDLE R	VALLEY	67b	AUGUSTA	38.19791	78.94310	3	FLOWING	Y	Y	N	Y	N
VA776S	TARGET	REMAP	1994	MOFFETT CR	VALLEY	67a	AUGUSTA	38.29563	79.16130	3	FLOWING	Y	Y	N	Y	N
VA777S	TARGET	REMAP	1994	CHRISTIANS CR	VALLEY	67b	AUGUSTA	38.18828	78.93710	3	FLOWING	Y	Y	N	Y	N
VA779S	TARGET	REMAP	1994	BLACKS RUN	VALLEY	67a	ROCKINGHAM	38.38243	78.92270	3	FLOWING	Y	Y	N	Y	N
VA780S	TARGET	REMAP	1994	CATLETT RUN	VALLEY	67b	WARREN	39.00368	78.27300	2	FLOWING	Y	Y	N	Y	N
VA781S	TARGET	REMAP	1994	PUGHS RUN	VALLEY	67a	SHENANDOAH	38.90603	78.49440	3	FLOWING	Y	Y	N	Y	N
VA782S	TARGET	REMAP	1994	CAPON RUN	VALLEY	67b	ROCKINGHAM	38.76608	78.91270	3	FLOWING	Y	Y	N	Y	N
VA783S	TARGET	REMAP	1994	ROSEVILLE RUN	VALLEY	67a	CLARKE	39.07206	78.04220	3	FLOWING	Y	Y	N	Y	N
VA784S	TARGET	TIME	1994	BACK CR	RIDGE	67c	BATH	38.24548	79.76470	3	FLOWING	Y	Y	N	Y	N
VA785S	TARGET	TIME	1994	NNT WARM SPRINGS RUN	RIDGE	67c	BATH	38.05223	79.78210	2	FLOWING	Y	Y	N	Y	N
VA786S	TARGET	REMAP	1994	HARMON RUN	VALLEY	67b	COVINGTON	37.76816	79.99420	2	FLOWING	Y	Y	N	Y	N
VA787S	TARGET	REMAP	1994	NNT MILL CR	VALLEY	67a	BOTETOURT	37.49019	79.79660	2	FLOWING	Y	Y	N	Y	N

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STRM_ID	SITECLS	STUDY	YEAR	STRMNAME	ECOAREA	ECOREG	COUNTY	LAT_DD	LON_DD	ORD	FLOWSITE	BENTH RBPHAB	FISH	FISH TISS	STRM CHEM	PHAB DO/TEMP
VA788S	TARGET	REMAP	1994	NNT JOHNS CR	VALLEY	67b	CRAIG	37.50177	80.22580	1	FLOWING	Y	Y	N	Y	N
VA789S	TARGET	TIME	1994	ELIBER SPRINGS BR	RIDGE	67c	CRAIG	37.40859	80.43810	1	FLOWING	Y	Y	N	Y	N
VA790S	TARGET	TIME	1994	NNT CRAB RUN	RIDGE	67c	HIGHLAND	38.30962	79.56260	1	FLOWING	Y	Y	N	Y	N
VA791S	TARGET	TIME	1994	SPY RUN	BLUERIDGE	66b	AUGUSTA	37.92481	79.15020	2	FLOWING	Y	N	N	Y	N
VA792S	TARGET	REMAP	1994	GOCHENOUR BR	VALLEY	67b	ROCKBRIDGE	37.93614	79.56650	1	FLOWING	Y	Y	N	Y	N
VA793S	TARGET	TIME	1994	NORTH FORK LONG BR BUFFALO R	BLUERIDGE	66a	AMHERST	37.75450	79.18770	1	FLOWING	Y	N	N	Y	N
VA794S	TARGET	TIME	1994	NNT REED CR	BLUERIDGE	66a	BEDFORD	37.48019	79.38600	1	FLOWING	Y	N	N	Y	N
VA795S	TARGET	TIME	1994	SWIFT RUN	BLUERIDGE	66a	GREENE	38.35645	78.53720	2	FLOWING	Y	N	N	Y	N
VA796S	TARGET	REMAP	1994	WRIGHT BR	VALLEY	67a	ROANOKE	37.33344	80.23940	1	FLOWING	Y	Y	N	Y	N
VA797S	TARGET	REMAP	1994	NNT BACK CR	VALLEY	67b	ROANOKE	37.20686	80.04270	1	FLOWING	Y	Y	N	Y	N
VA799S	TARGET	TIME	1994	LITTLE R	BLUERIDGE	66c	FLOYD	36.96157	80.24080	3	FLOWING	Y	N	N	Y	N
VA800S	TARGET	REMAP	1994	COVE CR	VALLEY	67a	WYTHE	36.98431	81.04610	3	FLOWING	Y	Y	N	Y	N
VA801S	TARGET	TIME	1994	GREASY CR	BLUERIDGE	66c	FLOYD	36.85614	80.45490	1	FLOWING	Y	N	N	Y	N
VA802S	TARGET	REMAP	1994	NNT NEW R	VALLEY	67b	WYTHE	36.88085	80.84840	2	FLOWING	Y	Y	N	Y	N
VA803S	TARGET	REMAP	1994	SOUTH FORK REED CR	VALLEY	67a	WYTHE	36.87528	81.24790	3	FLOWING	Y	Y	N	Y	N
VA805S	TARGET	TIME	1994	LICK CR	RIDGE	67c	SMYTH	36.97981	81.45410	3	FLOWING	Y	Y	N	Y	N
VA806S	TARGET	REMAP	1994	BEAVER CR	VALLEY	67a	SMYTH	36.88685	81.67430	2	FLOWING	Y	Y	N	Y	N
VA809S	TARGET	REMAP	1994	COPPER CR	VALLEY	67a	SCOTT	36.72147	82.48000	3	FLOWING	Y	N	N	Y	N
VA810S	TARGET	REMAP	1994	LITTLE CEDAR CR	VALLEY	67a	RUSSELL	36.91203	82.05560	3	FLOWING	Y	Y	N	Y	N
VA811S	TARGET	REMAP	1994	LITTLE COPPER CR	VALLEY	67a	RUSSELL	36.82144	82.26240	2	FLOWING	Y	Y	N	Y	N
VA812S	TARGET	REMAP	1994	INDIAN CR	VALLEY	67a	RUSSELL	36.98894	81.84320	2	FLOWING	Y	Y	N	Y	N
VA813S	TARGET	TIME	1994	WALLEN CR	RIDGE	67c	LEE	36.72050	82.87100	3	FLOWING	Y	Y	N	Y	N
VA816S	TARGET	TIME+	1994	THORNTON HOLLOW	BLUERIDGE	66a	RAPPAHANN	38.71250	78.30370	1	FLOWING	Y	N	N	Y	N
VA817S	TARGET	TIME+	1994	BULLPASTURE R	RIDGE	67c	HIGHLAND	38.20630	79.58440	3	FLOWING	Y	N	N	Y	N
VA818S	TARGET	TIME+	1994	KELLY RUN	RIDGE	67c	BATH	38.13920	79.78020	2	FLOWING	Y	N	N	Y	N
VA819S	TARGET	TIME+	1994	OLDFIELD CR	BLUERIDGE	66c	FLOYD	36.77060	80.45730	1	FLOWING	Y	N	N	Y	N
VA820S	TARGET	TIME+	1994	NNT ELK CR	BLUERIDGE	66c	GRAYSON	36.70050	81.07600	1	FLOWING	Y	N	N	Y	N
VA821S	TARGET	TIME+	1994	LITTLE WALKER CR	RIDGE	67c	PULASKI	37.14820	80.82290	3	FLOWING	Y	N	N	Y	N
VA822S	TARGET	TIME+	1994	BUCKEYE BR	BLUERIDGE	66c	WASHINGTON	36.61830	81.65490	2	FLOWING	Y	N	N	Y	N
WV501S	TARGET	EMAP	1993	ROCKY MARSH RUN		67a	JEFFERSON	39.45984	77.84214	2	FLOWING	Y	Y	Y	Y	Y
WV502S	TARGET	EMAP	1993	LOST CR.		APP-PLAT	HARRISON	39.16523	80.36043	3	FLOWING	Y	Y	Y	Y	Y
WV504S	TARGET	EMAP	1993	NONAME TRIB TURKEY RUN		APP-PLAT	MARSHALL	39.99999	80.54768	1	FLOWING	Y	Y	Y	Y	Y
WV505S	TARGET	EMAP	1993	MAULECAMP RUN		APP-PLAT	JACKSON	39.01983	81.60145	1	FLOWING	Y	Y	N	Y	Y
WV506S	TARGET	EMAP	1993	SPRUCE CR.		APP-PLAT	RITCHIE	39.07568	80.97332	3	FLOWING	Y	Y	Y	Y	Y
WV507S	TARGET	EMAP	1993	SMITH RUN		APP-PLAT	RITCHIE	39.12337	81.00001	1	FLOWING	Y	Y	Y	Y	Y
WV508S	TARGET	EMAP	1993	NONAME TRIB CARPENTER FORK	WESTAPPS	NSS-APP	BRAXTON	38.70319	80.58505	1	INTERUPT	Y	Y	N	Y	Y
WV511S	TARGET	EMAP	1993	NONAME TRIB LITTLE LAUREL CR.		NSS-APP	POCAHONTAS	38.32333	80.18488	1	FLOWING	Y	Y	Y	Y	Y
WV512S	TARGET	EMAP	1993	NONAME TRIB LAUREL BRANCH		NSS-APP	NICHOLAS	38.24382	80.78623	1	FLOWING	Y	Y	Y	Y	Y
WV513S	TARGET	EMAP	1993	HOLLYWOOD RUN		APP-PLAT	ROANE	38.62762	81.18240	1	FLOWING	Y	Y	N	Y	Y
WV514S	TARGET	EMAP	1993	MANILA CR.		APP-PLAT	PUTNAM	38.54768	81.79919	2	FLOWING	Y	Y	Y	Y	Y
WV515S	TARGET	EMAP	1993	HUFF CR.		APP-PLAT	WYOMING	37.74788	81.66496	3	FLOWING	Y	Y	N	Y	Y
WV516S	TARGET	EMAP	1993	MUD RIVER		APP-PLAT	LINCOLN	38.13519	82.03941	3	FLOWING	Y	Y	N	Y	Y
WV517S	TARGET	REMAP	1993	SOUTH FORK SOUTH BR POTOMAC		67b	PENDLETON	38.63848	79.22900	3	FLOWING	Y	Y	N	Y	N
WV518S	TARGET	TIME	1993	NONAME TRIB LUNICE CR		67c	GRANT	39.02202	79.11495	1	FLOWING	Y	Y	N	Y	N
WV519S	TARGET	TIME	1993	BOUSES RUN		67d	PENDLETON	38.68254	79.52031	1	FLOWING	Y	N	N	Y	N
WV520S	TARGET	TIME	1993	THORN CR		67c	PENDLETON	38.58042	79.35509	3	FLOWING	Y	Y	N	Y	N
WV521S	TARGET	REMAP	1993	NONAME TRIB SOUTH BR POTOMAC		67b	HARDY	39.07581	79.01189	1	FLOWING	Y	N	N	Y	N
WV522S	TARGET	TIME	1993	NONAME TRIB PATTERSON CR		67d	MINERAL	39.48851	78.84537	1	INTERUPT	Y	N	N	Y	N
WV523S	TARGET	TIME	1993	NONAME TRIB STONY	CENTAPPS	NSS-APP	GRANT	39.15161	79.32276	1	FLOWING	Y	N	N	Y	N
WV524S	TARGET	TIME	1993	TEAR COAT CR		67d	HAMPSHIRE	39.21740	78.68090	2	FLOWING	Y	Y	N	Y	N
WV525S	TARGET	TIME	1993	HOG RUN	BLUERIDGE	66b	JEFFERSON	39.17072	77.83544	1	FLOWING	Y	N	N	Y	N
WV527S	TARGET	TIME	1993	NONAME TRIB WOLF RUN CR		NSS-APP	BARBOUR	39.06215	79.93822	1	FLOWING	Y	N	N	Y	N
WV528S	TARGET	TIME	1993	SWAMP RUN		NSS-APP	UPSHUR	39.02210	80.06663	1	FLOWING	Y	N	N	Y	N
WV529S	TARGET	TIME	1993	DECKERS CR		NSS-APP	PRESTON	39.55794	79.80503	3	FLOWING	Y	N	N	Y	N

Appendix Table 2. Station locations, ecoregion designation, and parameters measured.

STRM_ID	SITECLS	STUDY	YEAR	STRMNAME	ECOAREA	ECOREG	COUNTY	LAT_DD	LON_DD	ORD	FLOWSITE	BENTH RBPHAB	FISH	FISH TISS	STRM CHEM	PHAB DO/TEMP
WV530S	TARGET	TIME	1993	SHAVERS FORK		67d	RANDOLPH	38.98110	79.73223	3	FLOWING	Y	Y	N	Y	N
WV531S	TARGET	TIME	1993	OTTER CR	CENTAPPS	NSS-APP	TUCKER	39.01117	79.64585	3	FLOWING	Y	N	N	Y	N
WV532S	TARGET	TIME	1993	GLADY FORK		67d	RANDOLPH	38.92928	79.62684	3	FLOWING	Y	Y	N	Y	N
WV533S	TARGET	TIME	1993	GLADY FORK		67d	RANDOLPH	38.90536	79.63556	3	FLOWING	Y	Y	N	Y	N
WV534S	TARGET	TIME	1993	BEAVER CR		NSS-APP	TUCKER	39.17729	79.40438	2	FLOWING	Y	N	N	Y	N
WV535S	TARGET	TIME	1993	DEVILS RUN		NSS-APP	TUCKER	39.09988	79.43606	1	FLOWING	Y	N	N	Y	N
WV536S	TARGET	REMAP	1993	NORTH BRANCH SNOWY CR		67b	PRESTON	39.43710	79.51440	2	FLOWING	Y	Y	N	Y	N
WV537S	TARGET	TIME	1993	LICK CR		NSS-APP	SUMMERS	37.48400	80.92124	3	FLOWING	Y	N	N	Y	N
WV538S	TARGET	TIME	1993	PIPESTEM CR		NSS-APP	SUMMERS	37.58376	80.91348	2	FLOWING	Y	N	N	Y	N
WV539S	TARGET	TIME	1993	SECOND CR		NSS-APP	MONROE	37.61096	80.43848	3	FLOWING	Y	N	N	Y	N
WV540S	TARGET	TIME	1993	NONAME TRIB GRIFFITH CR		NSS-APP	SUMMERS	37.75132	80.71082	1	FLOWING	Y	N	N	Y	N
WV541S	TARGET	TIME	1993	KELLY CR		NSS-APP	SUMMERS	37.66890	80.71319	3	FLOWING	Y	N	N	Y	N
WV542S	TARGET	REMAP	1993	SUGAR CAMP RUN		67b	POCAHONTAS	38.27621	79.88661	2	FLOWING	Y	Y	N	Y	N
WV543S	TARGET	TIME	1993	BURNING RUN		67d	POCAHONTAS	38.62641	79.65340	1	FLOWING	Y	Y	N	Y	N
WV544S	TARGET	TIME	1993	NONAME TRIB WOLF CR		NSS-APP	MONROE	37.69818	80.64094	1	FLOWING	Y	N	N	Y	N
WV545S	TARGET	TIME	1993	MILL CR	CENTAPPS	NSS-APP	FAYETTE	38.08542	81.02463	2	FLOWING	Y	N	N	Y	N
WV546S	TARGET	TIME	1993	TURKEY CR		NSS-APP	FAYETTE	38.13091	81.12441	1	FLOWING	Y	N	N	Y	N
WV547S	TARGET	TIME	1993	GAULEY		NSS-APP	WEBSTER	38.39908	80.49256	3	FLOWING	Y	N	N	Y	N
WV548S	TARGET	TIME	1993	NONAME TRIB SOUTH FORK CHERRY R.	CENTAPPS	NSS-APP	GREENBRIER	38.21401	80.47914	1	FLOWING	Y	N	N	Y	N
WV549S	TARGET	TIME	1993	NONAME TRIB MEADOW		NSS-APP	GREENBRIER	37.92823	80.69479	1	INTERUPT	Y	N	N	Y	N
WV550S	TARGET	TIME	1993	LEATHERWOOD CR		NSS-APP	CLAY	38.40722	81.09776	3	FLOWING	Y	N	N	Y	N
WV553S	TARGET	TIME	1993	BIRCH		NSS-APP	WEBSTER	38.42836	80.58348	2	FLOWING	Y	N	N	Y	N
WV554S	TARGET	TIME	1993	BACKFORK ELK RIVER		NSS-APP	WEBSTER	38.56048	80.29109	3	FLOWING	Y	N	N	Y	N
WV555S	TARGET	TIME	1993	WHITE OAK CR		NSS-APP	RALEIGH	37.93738	81.31760	1	FLOWING	Y	N	N	Y	N
WV750S	TARGET	EMAP	1994	CLIFFORD HOLLOW	RIDGE	67d	HARDY	39.13530	78.89680	2	FLOWING	Y	Y	Y	Y	Y
WV751S	TARGET	EMAP	1994	LAUREL FORK SAND RUN	CENTAPPS	APP-PLAT	UPSHUR	39.00300	80.13850	3	FLOWING	Y	Y	Y	Y	Y
WV752S	TARGET	EMAP	1994	RED RUN	CENTAPPS	NSS-APP	TUCKER	39.06010	79.52210	2	FLOWING	Y	Y	N	Y	Y
WV754S	TARGET	EMAP	1994	RESERVOIR HOLLOW	RIDGE	67d	POCAHONTAS	38.57520	79.75590	1	FLOWING	Y	Y	Y	Y	Y
WV755S	TARGET	EMAP	1994	POSSUM HOLLOW	RIDGE	67d	POCAHONTAS	38.17600	79.99410	2	FLOWING	Y	Y	Y	Y	Y
WV756S	TARGET	EMAP	1994	MOSSY CR	CENTAPPS	NSS-APP	FAYETTE	37.97040	81.24310	2	FLOWING	Y	Y	Y	Y	Y
WV757S	TARGET	EMAP	1994	CHESTNUT KNOB	CENTAPPS	NSS-APP	CLAY	38.46550	81.02590	1	FLOWING	Y	Y	Y	Y	Y
WV759S	TARGET	EMAP	1994	SPRUCE FORK	CENTAPPS	APP-PLAT	LOGAN	37.89050	81.82340	3	FLOWING	Y	Y	Y	Y	Y
WV760S	TARGET	EMAP	1994	PINNACLE CR	CENTAPPS	APP-PLAT	WYOMING	37.52220	81.43460	3	FLOWING	Y	Y	Y	Y	Y
WV761S	TARGET	EMAP	1994	NNT BOWEN CR	CENTAPPS	APP-PLAT	CABELL	38.29890	82.26910	1	FLOWING	Y	Y	N	Y	Y
WV765S	TARGET	TIME	1994	EDWARDS RUN	RIDGE	67c	HAMPSHIRE	39.28689	78.47620	2	FLOWING	Y	Y	N	Y	N
WV767S	TARGET	REMAP	1994	NNT SLEEPY CR	VALLEY	67b	MORGAN	39.55091	78.20910	2	FLOWING	Y	Y	N	Y	N
WV768S	TARGET	TIME	1994	BIG COVE RUN	CENTAPPS	NSS-APP	BARBOUR	39.24524	79.93500	1	FLOWING	Y	N	N	Y	N
WV769S	TARGET	TIME	1994	NNT LAUREL RUN	CENTAPPS	NSS-APP	RANDOLPH	38.87892	79.95630	1	FLOWING	Y	N	N	Y	N
WV770S	TARGET	REMAP	1994	MOSS RUN	VALLEY	67b	RANDOLPH	38.71513	79.96140	2	FLOWING	Y	Y	N	Y	N
WV771S	TARGET	TIME	1994	LEFT FORK CLOVER RUN	RIDGE	67d	TUCKER	39.16329	79.71270	3	FLOWING	Y	Y	N	Y	N
WV773S	TARGET	TIME	1994	SOUTH BR WOLF RUN	RIDGE	67d	PRESTON	39.24112	79.51490	1	FLOWING	Y	Y	N	Y	N
WV774S	TARGET	TIME	1994	LITTLE BLACK FORK	RIDGE	67d	RANDOLPH	38.97448	79.73340	1	FLOWING	Y	Y	N	Y	N
WV775S	TARGET	TIME	1994	SNOWY CR	CENTAPPS	NSS-APP	PRESTON	39.43141	79.50020	3	FLOWING	Y	N	N	Y	N
WV776S	TARGET	TIME	1994	LITTLE KNAWL CR	WESTAPPS	NSS-APP	BRAXTON	38.81372	80.55460	2	FLOWING	Y	N	N	Y	N
WV777S	TARGET	TIME	1994	ROCK CAMP CR	CENTAPPS	NSS-APP	MONROE	37.51628	80.61750	3	FLOWING	Y	N	N	Y	N
WV778S	TARGET	TIME	1994	NNT NEW R	CENTAPPS	NSS-APP	MONROE	37.43816	80.84270	2	FLOWING	Y	N	N	Y	N
WV779S	TARGET	TIME	1994	CLOVER CR	RIDGE	67d	POCAHONTAS	38.32607	79.98010	2	FLOWING	Y	Y	N	Y	N
WV784S	TARGET	TIME	1994	NNT LICK CR	CENTAPPS	NSS-APP	SUMMERS	37.81098	80.83060	1	FLOWING	Y	N	N	Y	N
WV785S	TARGET	TIME	1994	NNT GLADE CR	CENTAPPS	NSS-APP	RALEIGH	37.71447	81.04720	1	INTERUPT	Y	N	N	Y	N
WV786S	TARGET	TIME	1994	MCMILLION CR	CENTAPPS	NSS-APP	NICHOLAS	38.36529	80.79280	2	FLOWING	Y	N	N	Y	N
WV787S	TARGET	TIME	1994	NNT RIGHT FORK LINE CR	CENTAPPS	NSS-APP	NICHOLAS	38.28589	81.01850	1	FLOWING	Y	N	N	Y	N
WV788S	TARGET	TIME	1994	WHITE OAK FORK	CENTAPPS	NSS-APP	WEBSTER	38.35736	80.38310	1	FLOWING	Y	N	N	Y	N
WV790S	TARGET	TIME	1994	FALLING ROCK CR	CENTAPPS	NSS-APP	KANAWHA	38.46451	81.39770	2	FLOWING	Y	N	N	Y	N
WV792S	TARGET	TIME	1994	LEATHERWOOD CR	CENTAPPS	NSS-APP	RANDOLPH	38.43868	80.17610	1	FLOWING	Y	N	N	Y	N

Appendix Table 2. Station locations, ecoregion designation, and parameters measured.

STRM_ID	SITECLS	STUDY	YEAR	STRMNAME	ECOAREA	ECOREG	COUNTY	LAT_DD	LON_DD	ORD	FLOWSITE	BENTH RBPHAB	FISH	FISH TISS	STRM CHEM	PHAB DO/TEMP
WV794S	TARGET	TIME+	1994	BEAVER CR	CENTAPPS	NSS-APP	BARBOUR	38.96600	79.95790	3	FLOWING	Y	N	N	Y	N
WV795S	TARGET	TIME+	1994	BECKY CR	RIDGE	67d	RANDOLPH	38.60940	79.96950	2	FLOWING	Y	N	N	Y	N
WV796S	TARGET	TIME+	1994	RED CR	CENTAPPS	NSS-APP	TUCKER	39.03940	79.33730	2	FLOWING	Y	N	N	Y	N
WV797S	TARGET	TIME+	1994	LICK RUN	CENTAPPS	NSS-APP	PRESTON	39.41970	79.72410	2	FLOWING	Y	N	N	Y	N
WV799S	TARGET	TIME+	1994	LAUREL CR	CENTAPPS	NSS-APP	WEBSTER	38.52380	80.57820	3	FLOWING	Y	N	N	Y	N
WV800S	TARGET	TIME+	1994	JIMS FORK	CENTAPPS	NSS-APP	KANAWHA	38.35840	81.42990	1	FLOWING	Y	N	N	Y	N
MDT01S	TEST	TEST	1993	CHERRY CREEK		NSS-APP	GARRETT	39.53750	79.31500		FLOWING	Y	Y	N	Y	N
MDT02S	TEST	TEST	1993	TROUT RUN		67b	GARRETT	39.38830	79.39310		FLOWING	Y	Y	N	Y	N
MDT03S	TEST	TEST	1993	BRADDOCK RUN		67c	ALLEGANY	39.67080	78.79360		FLOWING	Y	Y	N	Y	N
PAT01S	TEST	TEST	1993	LOGAN BRANCH		67a	CENTRE	40.90670	77.77940		FLOWING	Y	Y	N	Y	N
PAT02S	TEST	TEST	1993	NONAME TRIB PINE CREEK		67a	CENTRE	40.89110	77.39360		FLOWING	Y	Y	N	Y	N
PAT03S	TEST	TEST	1993	SOUTH BRANCH ROARING CREEK		67b	COLUMBIA	40.89970	76.51170		FLOWING	Y	Y	N	Y	N
VAT01S	TEST	TEST	1993	PEAK CREEK		67c	PULASKI	37.04330	80.74810		FLOWING	Y	Y	N	Y	N
VAT02S	TEST	TEST	1993	CRAB CREEK		67a	MONTGOMERY	37.15670	80.46970		FLOWING	Y	Y	N	Y	N
WVT01S	TEST	TEST	1993	EAST FORK GREENBRIER RIVER		67d	POCAHONTAS	38.54280	79.81690		FLOWING	Y	Y	N	Y	N
WVT02S	TEST	TEST	1993	HELL RUN		NSS-APP	BARBOUR	38.95050	80.07250		FLOWING	Y	N	N	Y	N